(2)

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Description of the Bistatic Radar Terrain Measurements System Equipment

Edward H. Jocoy, et al
Calspan Corporation
Buffalo, N.Y. 14225

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WRIGHT RESEARCH DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6543

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Thomas L. Madden

THOMAS L. MADDEN
Project Engineer
EW Adv Dev Program Group
ECM Adv Dev Br, EW Division
Avionics Laboratory

David A. Hime

DAVID A. HIME, Chief
EW Adv Dev Program Group
ECM Adv Dev Branch
EW Division
Avionics Laboratory

FOR THE COMMANDER

John E. Tfhan

JOHN E. TFHAN, Chief
Electronic Warfare Division
Avionics Laboratory

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The objective of this program was to collect a data base of X-band, bistatic terrain reflectivity data to aid in the design and evaluation of the Electronic Warfare (EW) Systems. Airborne radar platforms were used to obtain data from various types of terrain at various incidence, reflection and out-of-plane angles. Both static and dynamic tests were conducted. The principal reflectivity measure derived from the data was the bistatic reflection coefficient ($\sigma°$) as a function of angle. Spectra were obtained from the dynamic tests. — RH

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19. ABSTRACT (Cont'd.)

This report, the first of two technical reports on the program, describes the design of the experiments and the data acquisition techniques, the equipment design and fabrication, calibration techniques and system software.

Tests were conducted over desert land at White Sands Missile Range, range land in Montana, pine forests at Eglin Air Force Base and a deciduous tree-covered area near Syracuse, NY. The equipment was installed in two US Army UH-1 helicopters to serve as radar platforms. Static data were collected with the helicopters hovering. For the dynamic test the transmitter equipment was installed in a Calspan owned Piper Aztec twin engine aircraft. The Aztec aircraft was flown towards the hovering receiver helicopter. A microwave landing system was used to measure and control the positions of the aircraft in both the static and dynamic tests.

Data reduction techniques, results and analysis will be published in the final report scheduled for publication in December 1990.

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The research program reported herein was administered by the Avionic Laboratory. Capt. Verle Johnson served as Program Monitor during the equipment development and early testing. Thomas Madden replaced Capt. Johnson during the later portions of the program. Dr. E.H. Jocoy served as the Calspan Program Manager during the design, fabrication and majority of testing. Mr. T.F. Leney was the Calspan Program Manager since March of 1989.

Ms. M.A. Rude contributed to much of the overall system design and, in particular, the RF systems and also served as a flight crew member. More recently she served as the field test director. Mr. N.E. Schweitzer was responsible for the data acquisition system, the software development for the Masscomp computer and the interaction of terrain measurement equipment with aircraft systems. He also contributed to the stabilization system modifications and was the test director for much of the remote operations as well as a flight crew member. Ms. L.M. Sheldon and Mr. J.R. Gucwa contributed to the realtime software development as well as the data reduction software. They also served as flight crew. Messrs. B.R. Felder and M.G. Koscielny provided equipment maintenance support as well as serving as flight crew. Mr. J.B. Snelting was responsible for the design and fabrication of the RF systems. Dr. G.P. Halsted and Mr. B.H. Mohlke contributed to the design of the experiments and data requirements, as well as data reduction algorithms and analysis. Dr. D.J. Gawlowicz contributed to stabilization system modification. Messrs. C.W. Wightman and R.A. Ratajczak contributed to the data link and test geometries respectively. Ms. Lisa Wegryn served as data base manager.

The Calspan Flight Research Department provided hangar space and technical support. In particular, Mr. J.R. Bellman provided technical guidance for many of the initial shakedown flight and was instrumental in securing the microwave landing system.

Mr. R.W. Huber of the Calspan Flight Research Department served as the flight test pilot of the Aztec aircraft along with R.P. Deppe and J.E. Priest. Messrs. J.A. Orris and E.W. Ernle provided maintenance of the Aztec aircraft.

Calspan wishes to thank Lt. Col. Fanning of the Army Electronics Research Activity (AERA) and his staff for providing the helicopter support and in particular chief test pilot Thomas McNamara and the pilot crew.

The Army Communications Electronics Command at Ft. Monmouth, NJ, supervised the equipment installation and designed many of the aircraft modifications. Mr. John Miller was the principal engineer.

Special thanks go to Lt. Col. Kuhn of the U.S. Army Air National Guard for providing hangar space and support during the shakedown flights at Niagara Falls Air Base in Western New York.

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Section 1

INTRODUCTION

This interim report describes the design, fabrication and installation of an airborne X-band radar system for measuring bistatic reflection (forward scatter) from various types of terrain. More than 34 hours of data have been collected and analyzed for 5 different types of terrain with the system. The data analysis and results will be presented in a separate final report.

The Terrain Measurements program, initiated in 1984, had the following objectives:

- Develop a data base of bistatic terrain reflectivity data for Electronic Warfare (EW) applications.
- Collect validation data for reflectivity models such as the Calspan/USAF Terrain Effects Model (TEM). Validate TEM.
- Include both:
    - Static data (hovering helicopters)
    - Dynamic data (fixed wing aircraft and hovering helicopter)

In addition to the EW application, the data has application in the area of Air Defense Initiatives and in general radar design. The primary output of the measurement system is reflectivity data in terms of the bistatic scattering coefficient, $\sigma°$, as a function of incidence, reflection and out-of-plane angle.

For the primary tests, two hovering helicopters were used as radar platforms, their altitudes and separations providing a wide variety of different geometries. Although a somewhat hostile (high vibration) environment, the helicopters do provide great flexibility in moving from site-to-site and within a site. In addition to tests with hovering helicopters (designated "static" tests), effects of spectral spreading were examined in "dynamic" tests by removing the transmitter from the transmit helicopter and installing it in a fixed wing aircraft which was flown toward the hovering receive helicopter.

The program was divided into 7 tasks:

- I Approach, Design and Planning
- II Fabrication and Installation
- III Bistatic Terrain Data Collection
- IV Data Analysis and Model Verification
- V Measurement of Spectrum Spread
- VI Documentation
- VII Management

Only the first two tasks are discussed in this report.

A chronology of significant events is given in Figure 1. Much of the system design, fabrication and installation took place between May 1984 and December 1986. Subcontractors were utilized for two major subsystems: the antennas and the stabilization systems. Subcontracts were let to CHU Associates for the antennas and D^2C for the stabilization system in April 1985 and May 1985, respectively. Other major non-Calspan efforts included modification of the microwave landing system after it was learned that the government could not make two glideslope units available, and one would have to be modified to accommodate position computations out to ±55° azimuth. In addition, a telemetry system was designed and built by Aydin-Vector. As installation of the large 4' receive antenna approached, the Army Aviation System Command (AVSCOM) became concerned about an engine-out descent in which significant air blockage would be caused by the receive antenna sticking

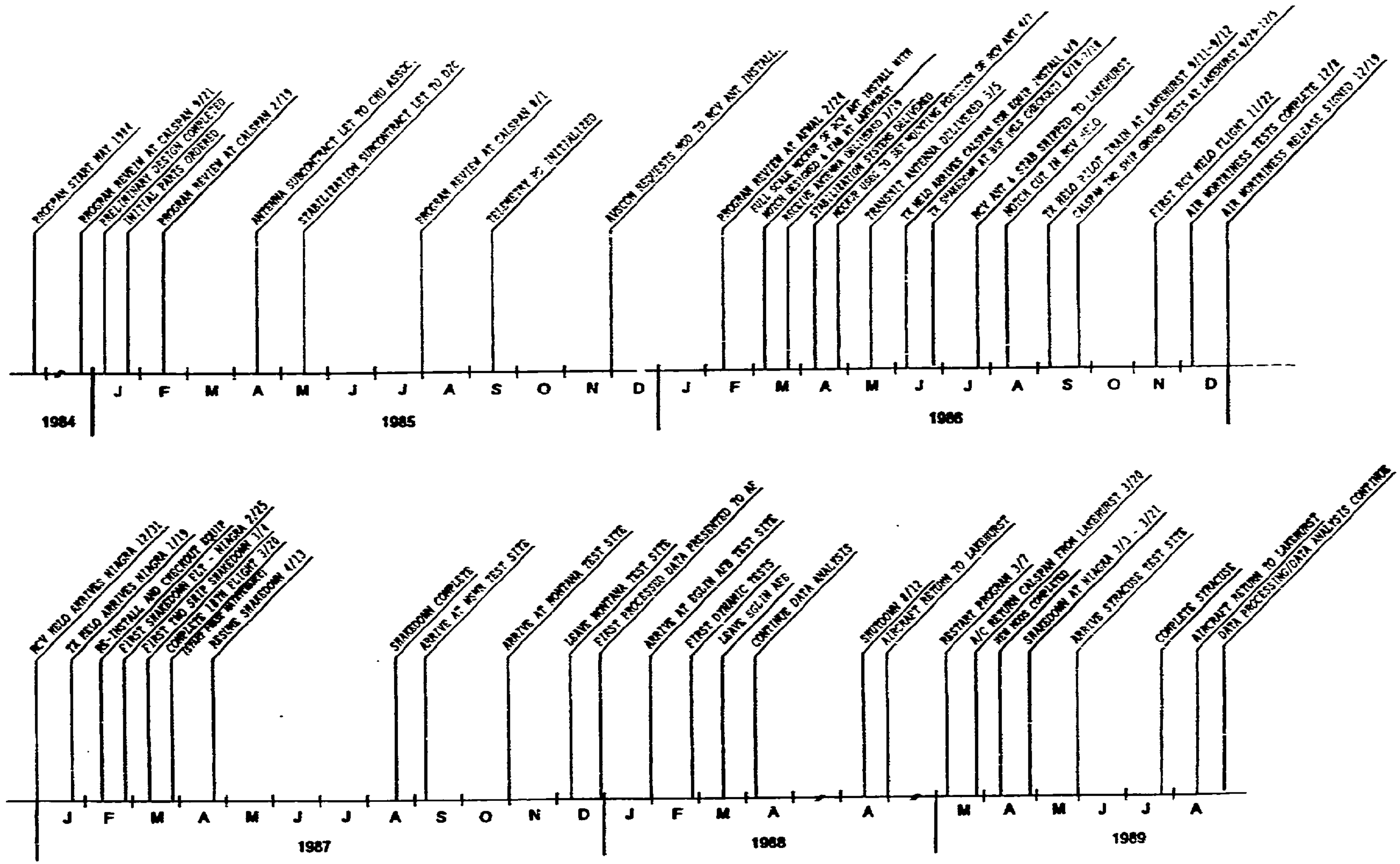


Figure 1. TERRAIN MEASUREMENTS PROGRAM CHRONOLOGY OF EVENTS

out the side of the receive helicopter. Consequently, in December of 1985, they requested the Army (CECOM) to cut a notch in the receive helicopter roof so that the antenna could be brought as close to the receive helicopter as possible (the door opening is not sufficient to accommodate the antenna). This was accomplished by AERA (Army Electronic Research Activity), Lakehurst, New Jersey, in August of 1986. While the simpler transmit system was flight tested in June 1986, the receive ship did not go through air worthiness tests until November-December 1986. By January of 1987, both ships were hangared at Niagara Falls Air Base in the U.S. Army Hangar 20 miles North of Buffalo. Eight months of shakedown flights followed during which significant difficulties were encountered with the data collection software and the stabilization systems, primarily the receive antenna stabilization system. Shakedown was completed in August 1987 and Calspan proceeded to White Sands Missile Range as the first two test sites for data collection which lasted to mid-November. Data collection over range land in Montana took place in November-December of 1987 and then at Eglin AFB in February-March of 1988. Due to funding problems, the program was shut down in August of 1988 and the did not resume until 7 months later on 7 March 1989. Data were collected at a site near Syracuse, New York in June and July of 1989. Upon completion of the Syracuse site, the helicopters were returned to Buffalo. All project equipment was removed (in preparation for a major phase maintenance of the aircraft) and the aircraft returned to Lakehurst, New Jersey.

Section 2

OVERVIEW OF TERRAIN MEASUREMENT SYSTEM

The terrain measurements system consists of a data collection system for collecting "static" data (two hovering helicopters) along with data collection and reduction software. In addition, the system has the capability for the collection of "dynamic" data by transferring the transmitter to a fixed wing aircraft which flies toward one hovering helicopter.

2.1 DATA COLLECTION PROCEDURE - STATIC MODE

2.1.1 Overview

Figure 2 illustrates the terrain measurements data collection scenario. Two U.S. Army UH-1 helicopters serve as radar platforms: one containing the transmitter, the other containing the receiver. Hovering at about 1500 ft AGL and 1 to 4 miles apart, the receive antenna (a 4-ft reflector with a 1.8° beam) scans the ground between the helicopters that has been flooded by the transmit antenna (30° beamwidth). The receive antenna scans continuously from 2° depression to 30° depression collecting 200-pulse "gulps" of data every 2°. (This is called the regular scan. A higher resolution scan will be discussed later.) The antenna is indexed in azimuth in 2° steps to cover a sector up to 20° or more wide. Three elevation scans are made at each azimuth position: one for vertical polarization, one for horizontal and one for right circular. The helicopters are positioned by the pilots, using information obtained from a microwave landing system (MLS) on the ground. Desired helicopter positions (relative to the MLS) are stored in the on-board computer and subtracted from the actual positions. The error signal is presented to the pilot who maneuvers the aircraft to minimize the error. In any case, actual position data are digitally recorded in the receive helicopter along with the radar signals and are used in the data reduction process to determine the actual geometry.

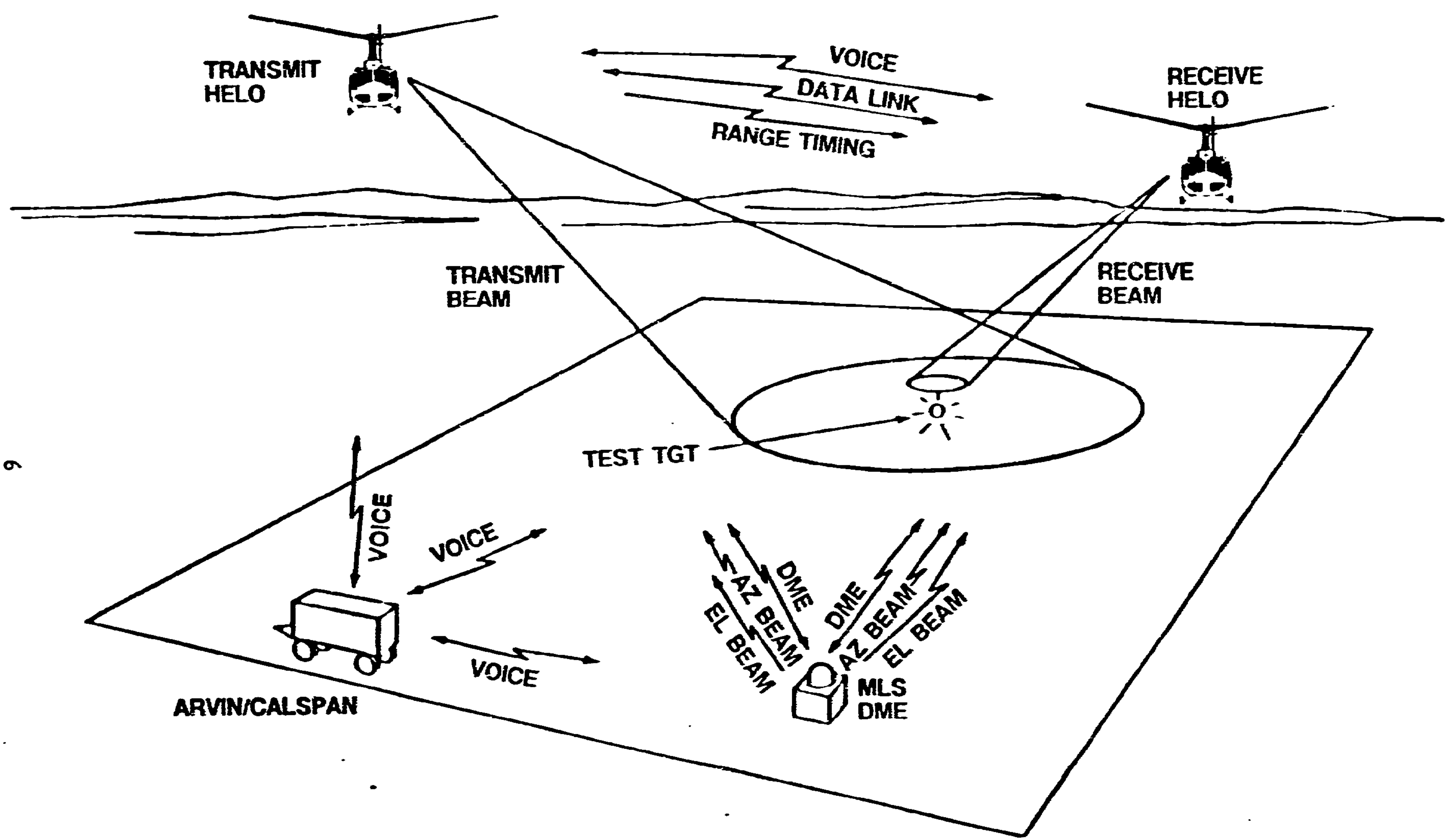


Figure 2. Terrain Measurements - Data Collection Scenario

The MLS position is accurately located on a geological survey map, and the aircraft are located in MLS coordinates which means the aircraft positions are known in map coordinates. Knowing the helicopter positions, the pointing angle of the antenna and the height of the terrain being measured (from the digitized geological survey map), the incidence, reflection and out-of-plane angles can be computed and associated with every gulp of radar data. (Note that, although the elevation scan is continuous, the motion of the antenna during a 200-pulse gulp is insignificant.)

2.1.2 Geometries

A geometry is defined by the specular angle (incidence equals reflection angle, zero out-of-plane angle). The specular angles were selected so that as the receive antenna scans, not only would data at specular be obtained, but a range of incidence/reflection angles pertinent to ECM applications would be covered. The primary specular angles that were selected are 26°, 20°, 14°, 10°, 6° and 4°. Unfortunately, a number of constraints were encountered both before and after the design of the data collection experiment that precluded collecting much data at 6° and 4°.

Figure 3 shows the geometry of the data collection process. The x, y, and z positions of the helicopters are given in Table 1. The x coordinate is called the MLS baseline. The system constraint s which in turn constrained the helicopter positions are as follows:

1. Flight safety considerations required that the helicopters hover no lower than 1000' AGL.

2. The maximum azimuth coverage of the MLS is about ± 55°.

3. The maximum elevation coverage of the MLS is about 4° to 14°.

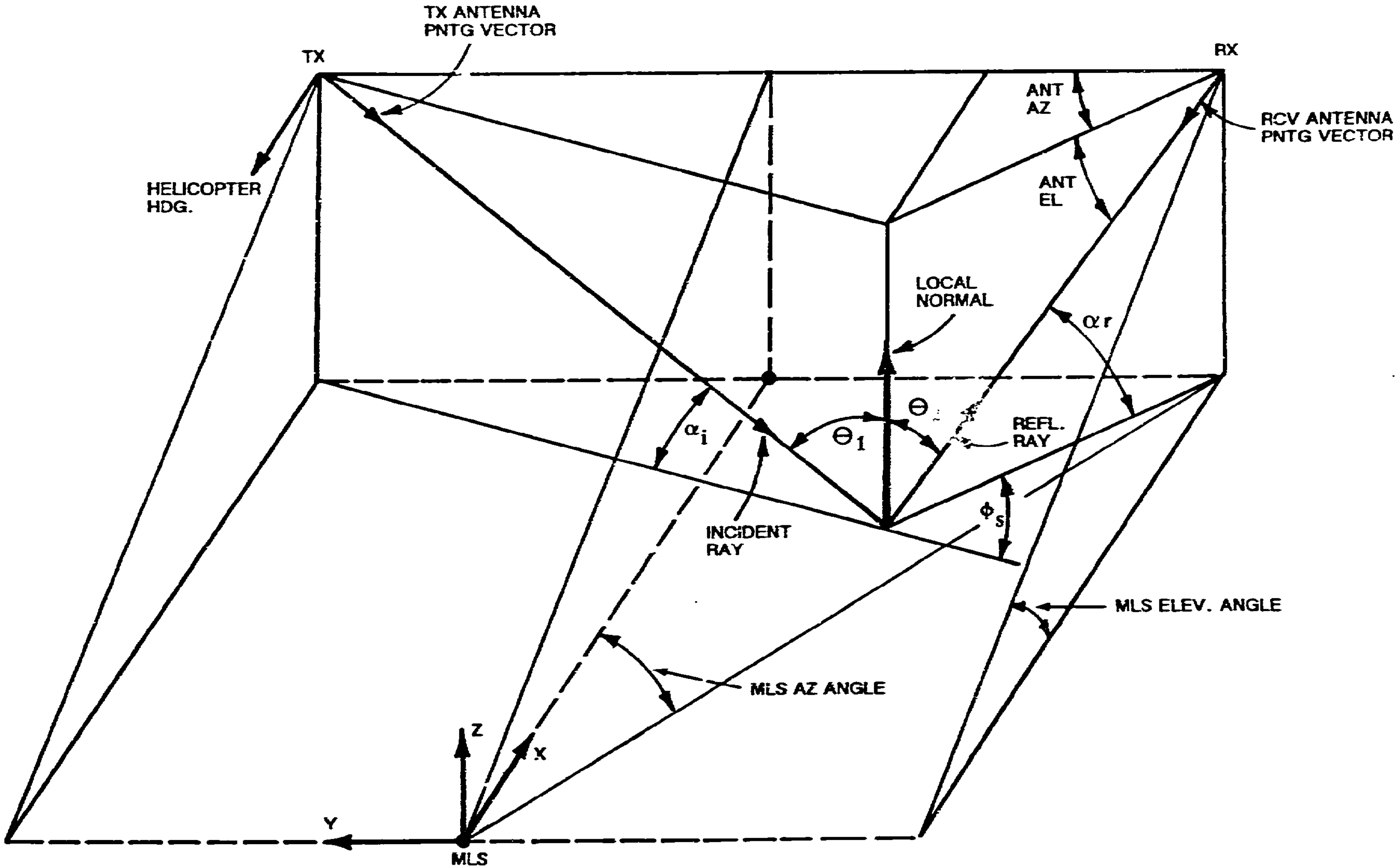


Figure 3. GEOMETRY AND ANGLE DEFINITIONS

Table 1
NOMINAL GEOMETRIES

Geometry (Specular Angle, deg)	X (Ft)(1) Relative to MLS	± Y (Ft) (1) Relative to MLS	Z (Ft) (1) Relative to Specular Point
26	7500	3260	1590
20	7500	4368	1590
14	7500	6377	1590
10	7500	8394	1480
6	7500	9838	1034
6(2)	11172	9514	1000
4(2)	11172	14301	1000

(1) For WSMR. See Section 8 for other sites.

(2) Data collection at long baseline geometries unsuccessful because of MLS limitation.

The MLS coverage constraints force the steep specular angles to be obtained with shorter y positions (instead of arbitrarily increasing altitude) and lower specular angles with longer y positions. The minimum altitude constraint forces longer MLS baselines in order to achieve the 4° specular.

The x, y and z positions for different geometries are stored in the in-flight computer prior to data collection and are called up as the data collection process progresses. The pilots then re-position the aircraft and another geometry is interrogated.

Another helicopter-imposed constraint is that they must hover generally into the wind. (They can accommodate changes up to about ± 20° around the general wind direction.) The heading of the MLS is therefore 180° from the aircraft heading. This presents no restriction on the geometries but does mean that the desired type of terrain must be available over a larger region on the ground then is strictly necessary for data collection. This is necessary in order that the geometry can be oriented so that the aircraft can be generally headed into the wind as the wind changes direction from day to day (see Section 2.1.8). It is desirable to keep the MLS at the same location, rotating it to accommodate long-term changes in wind direction.

2.1.3 Scan Raster and Data Collection Time

Although the receive antenna physically scans from 2° depression to 32° depression, data are not always collected over that range. Constraints are applied that limit the recording of the radar data. (One constraint is that elevation angles must be within the area illuminated by the tramsmit beam, which is pointed at specular.). Figure 4 shows the incidence and reflection angles for all the geometries (except 4°) for the in-plane, flat-terrain case. The nominal data collection points are indicated by the dots. Data are reduced by averaging data collected in an angle bin around the nominal 2° increments of receive antenna (reflection) angle. These bins are set in the data reduction process. Consequently, the multiple samples

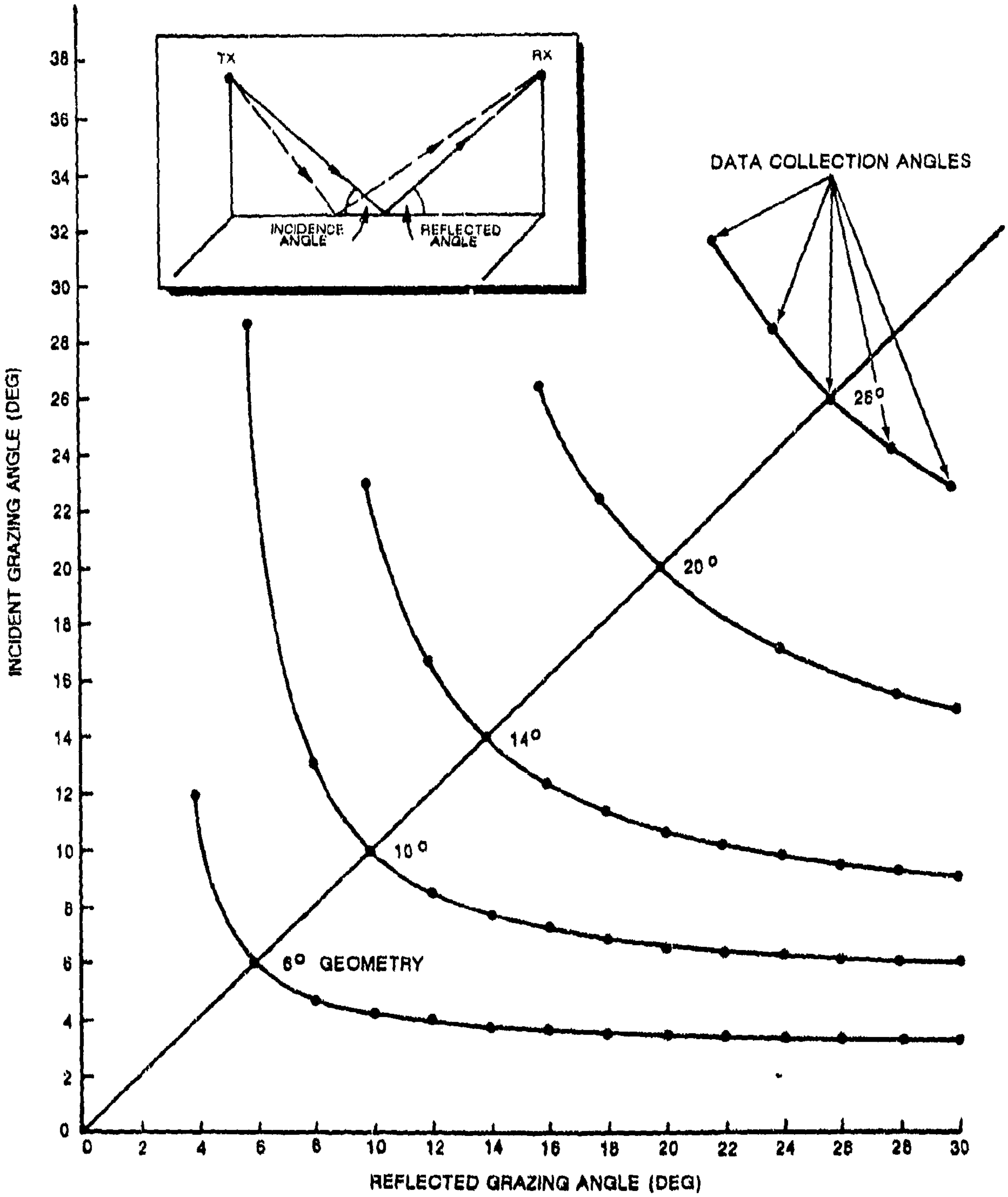


Figure 4. NOMINAL RANGES OF INCIDENCE AND REFLECTION ANGLES IN DATA COLLECTION (REGULAR SCAN, IN-PLANE ONLY, FLAT TERRAIN)

a given angle combination required for statistical accuracy don't have to be collected at precisely the same combination (which would be virtually impossible). The samples of some angle combinations may be collected during the course of a day or even over several days if soil conditions remain the same.

The complete scan raster is depicted in Figure 5. Three elevation scans are made at each azimuth position to receive each of 3 transmitted polarizations (vertical, horizontal and right circular). At the top or bottom of the elevation scan the antenna pauses for about 3 seconds before proceeding with the next elevation scan or indexing to the next azimuth. The indexing time is about 1/2 second. With an elevation scan rate of 6°/second, each elevation scan takes about 5 seconds. To cover an entire raster (called a data set) requires 5 minutes. During this 5-minute data set, radar data along with other data (including position data, antenna angle data, and radar parameter data) are recorded.

The helicopters carry about 1-1/2 hours of fuel. During this time, about 6-10 data sets can be collected (some data sets require repositioning the helicopters). Data at over 1000 combinations of incidence, reflection and out-of-plane angle can be collected in 1-1/2 hours for each of 3 polarizations. Two 1-1/2 data collection sessions can be accomplished in a day depending on weather and other factors.

In order to collect "finer grain" data at certain spots on the ground (such as the specular point), a "high resolution" scan was implemented. This "mini" scan covers 15° in elevation and 10° in azimuth in 1° increments with the scan sector centered on the nominal specular angle. Figure 6 shows the elevation scan pattern. Unfortunately, this modification to the regular scan pattern was not implemented until just before the last site.

2.1.4 Signal Sampling

2.1.4.1 Footprints and Range Rings. Figure 7 shows a sketch of the beam footprint on flat ground at a particular point in the

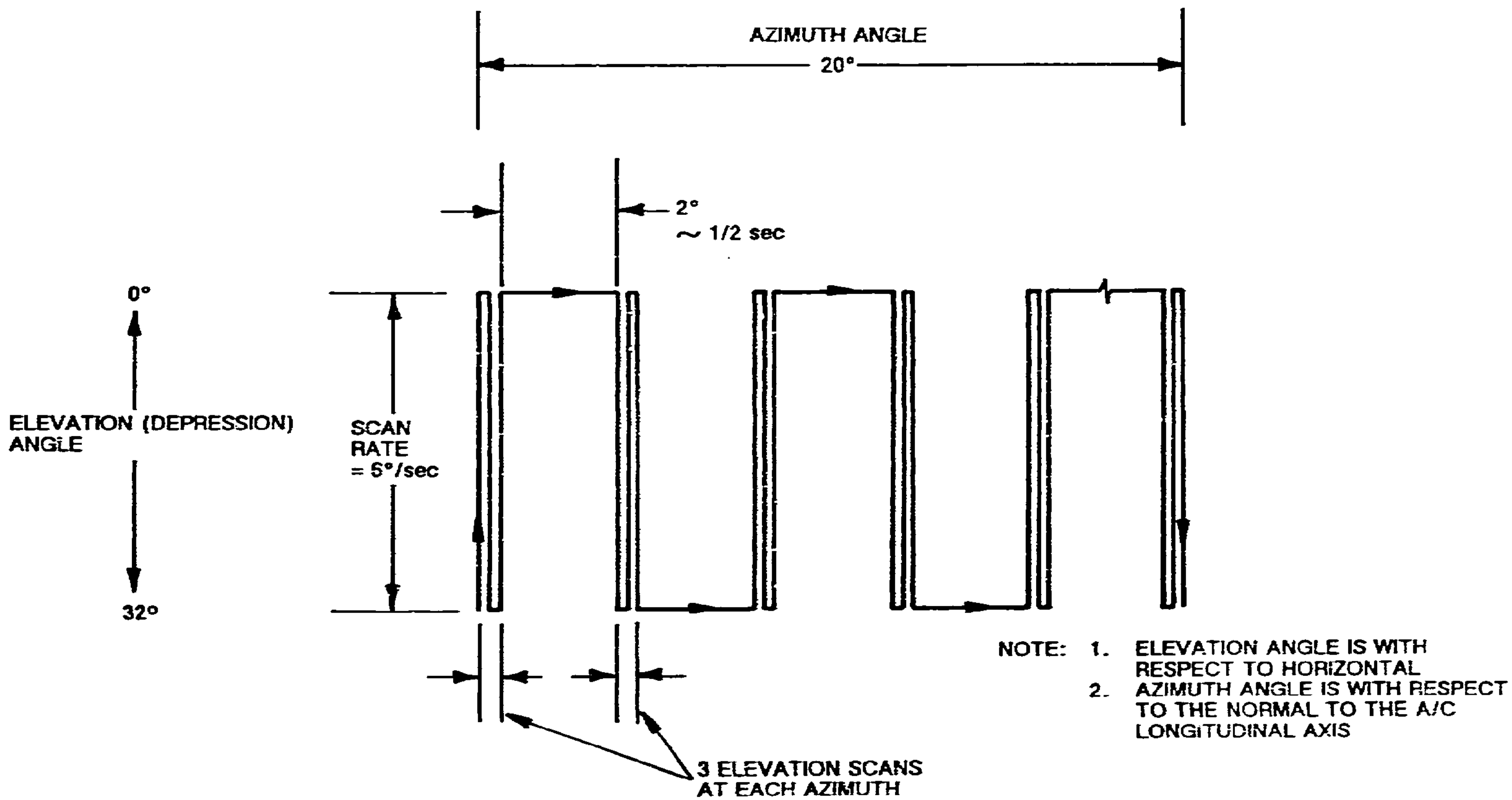


Figure 5. RECEIVE BEAM ELEVATION/AZIMUTH SCAN RASTER (REGULAR SCAN)

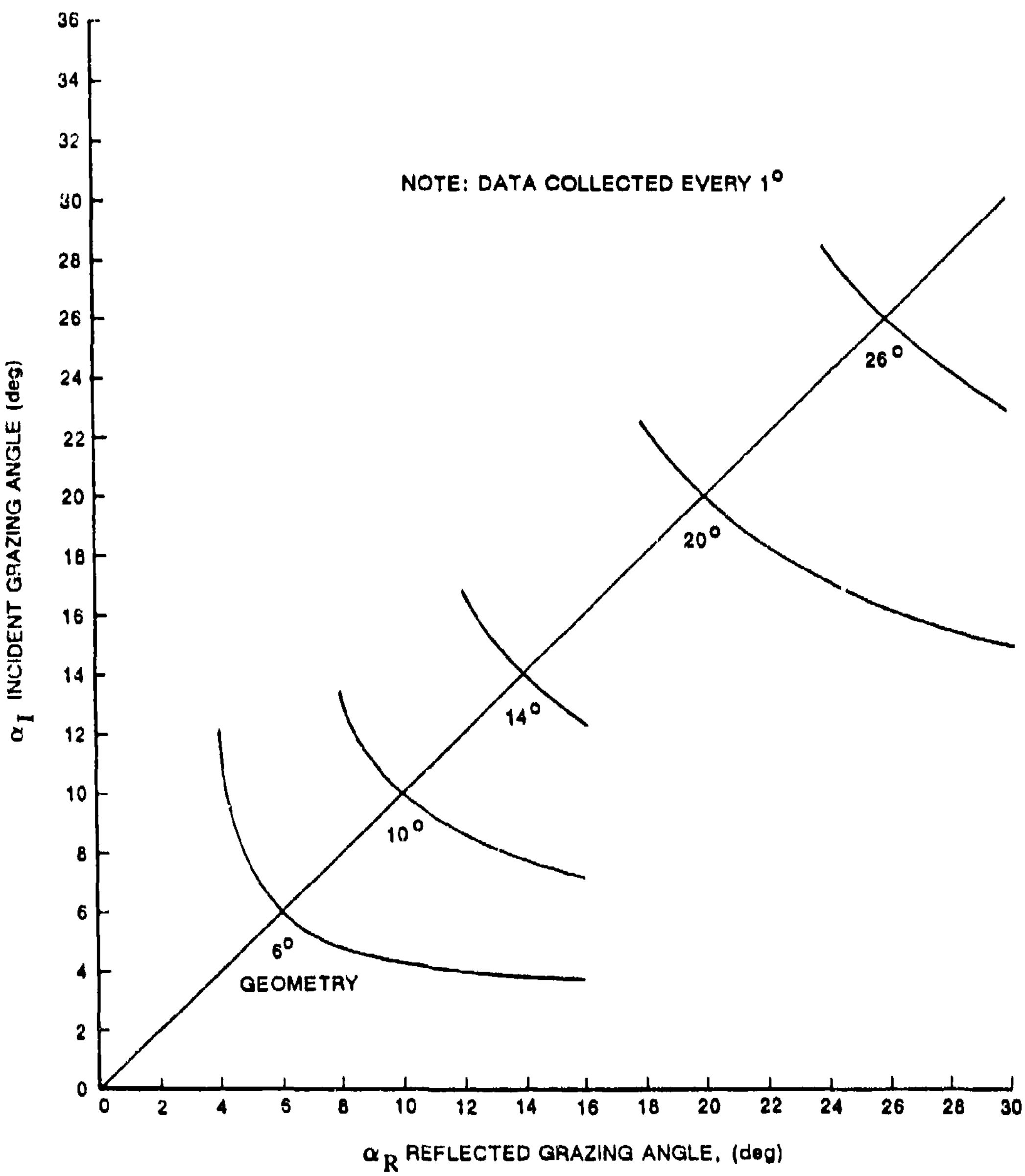


Figure 6. NOMINAL RANGES OF INCIDENCE AND REFLECTION ANGLE IN DATA COLLECTION (HIGH RESOLUTION SCAN, IN-PLANE ONLY, FLAT TERRAIN)

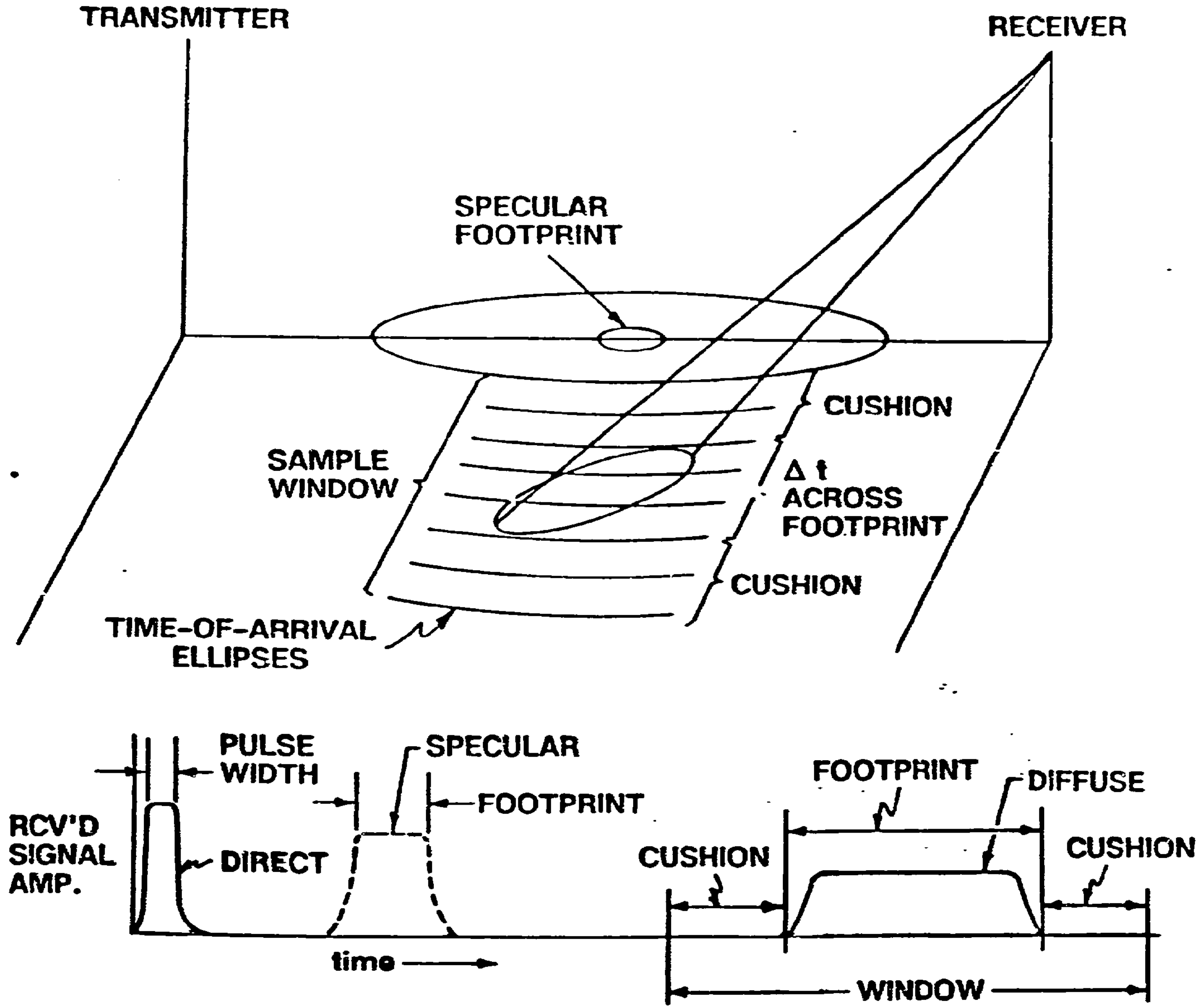


Figure 7. Sketch of Beam Footprint and Received Signals

receive beam scan raster. Also shown are segments of the constant time-of-arrival (range) rings. These rings are constant T.O.A. ellipses which are typically separated by a pulse length, or in our case, one-half pulse length. A sketch of the time history of the received signal shows that the first signal received is the unwanted direct signal followed by the signal from the specular point and then the primary signal from the footprint. (If the footprint were on the specular point, it would be the primary signal.) The direct and possibly the specular (depending on terrain type) will be strong enough to come in through sidelobes. In the sketch, the footprint is shown to encompass several T.O.A. rings. Also indicated is a "cushion" time interval which is added to either side of the footprint. At every 2° during the elevation scan of the receive antenna, the time window shown in Figure 7 is opened and data are collected. (Computer constraints preclude collecting data continuously during an entire elevation scan.) The time window is established by computing (before data collection) the footprint T.O.A. based on geometry and then adding a cushion to insure that the desired footprint signals are within the window. Extremely large differences in helicopter position from the desired position could result in the footprint signal falling outside the data collection window. This is flagged in the data reduction routine but nevertheless the data for that footprint is lost. During the window, 200 time samples of the received I and Q signals are taken. The distribution of these samples across the window will be discussed later.

Figure 8 expands on Figure 7 and shows three different footprints during an elevation scan. Note that, while the half-power footprints are adjacent to each other (2° increments and a 2° (approximate) half-power beamwidth), the times of arrival of the signals overlap. That is because the footprints intercept common TOA rings. Also note the time stretching of the footprint as grazing angle decreases.

2.1.4.2 Time Distribution of Samples. As previously mentioned, digital data storage limitations make it impossible to collect data during an entire elevation scan. Therefore, "snapshots" or a "window" of data are collected periodically (every 2° of elevation in this case) in 200 pulse "gulps". This restricts the amount of digitized data collected at

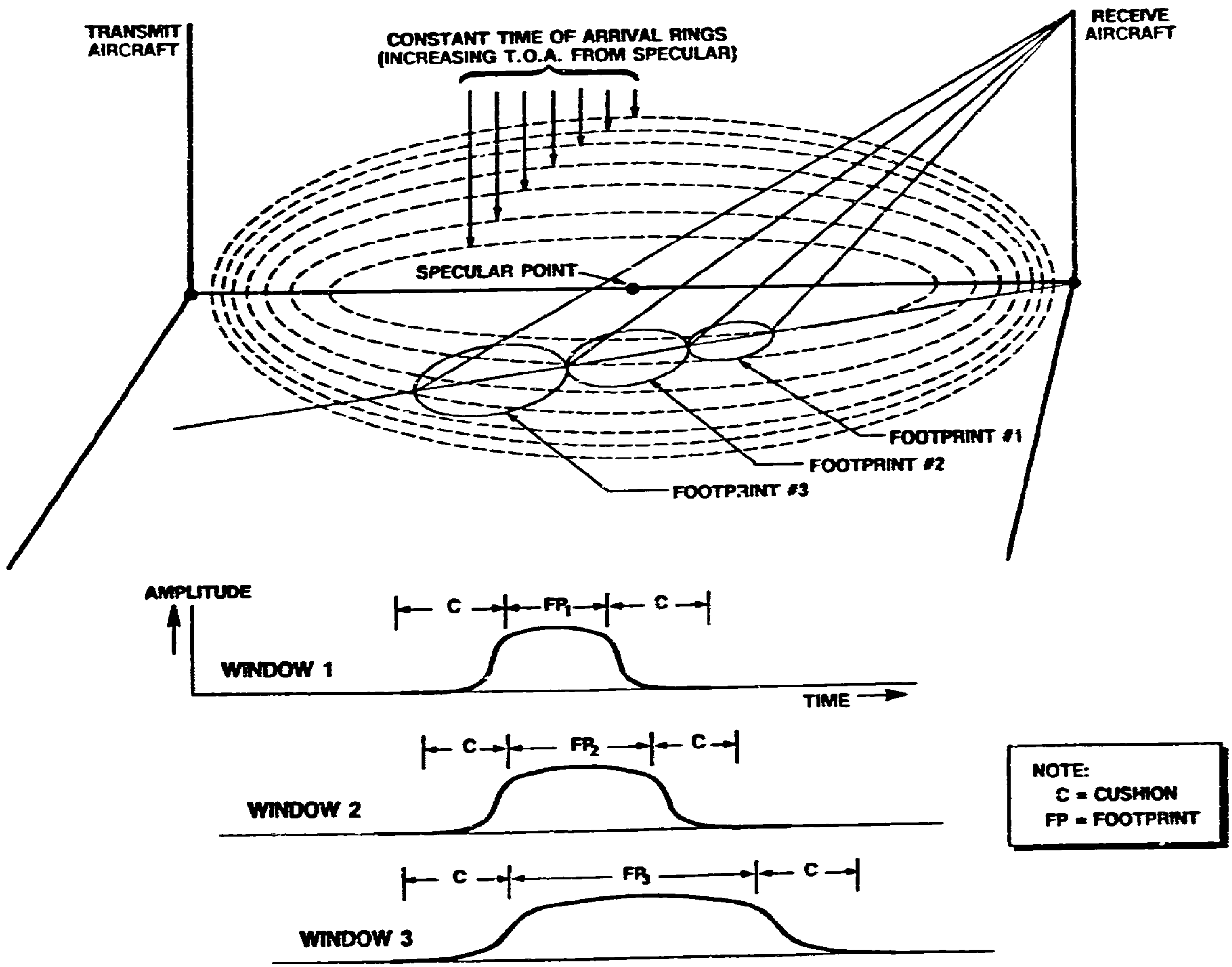


Figure 8. Sketch Relating Receive Antenna Footprints, Time-of-Arrival Rings, and Data Windows

any angle to a workable amount that can be transferred from buffers to disk before the start of another gulp. The 200-pulse constraint results from the fact that 3000 bytes are the maximum number of bytes that can be transferred through the data storage buffers from the start of data collection at one angle to the start of data collection at the next angle two degrees away in elevation. The buffers serve all channels including 6 RF signals each having I&Q video and two other data channels for receive antenna elevation and azimuth for a total of 14 channels. The 14 channels times the 200 pulses per channel results in 2800 bytes which is within the 3000-byte limit. The 200 pulses are distributed over a window as discussed in the next paragraph.

The window typically includes more than one time delay. Within the window a number of samples are distributed across the time delays. The real-time sequence of these samples relative to a PRI is shown in Figure 9. When the desired angle is reached during an elevation scan (in our case at integer increments) which coincides with the angle for data collection (an angle "match"), control signals are sent to start sampling the video return. Every PRI a timing pulse is received followed by the main transmitted pulse followed by the terrain signals. The same terrain signals can be sampled several times but only once every PRI. The first sample within the window occurs at the first, or starting delay, after the timing pulse. During the next PRI, the next sample either occurs at the same time delay after the timing pulse or at the next incremental time delay. Since 200 samples can be distributed across the time delays within a window, multiple samples at the same time delay frequently occur as shown in Figure 9. This is desirable for enhancing the signal-to-noise ratio of a terrain sample in the data reduction process. Upon completion of the sampling within a window, the search for the next desired elevation angle starts and when the elevation scan progresses to the next angle match the sampling within the next window begins. Figure 10 depicts the sampling within the windows in non-real-time and shows the overlap of the windows. The time delays for one entire elevation scan are computed prior to data collection and are stored in a Berkley counter. Control signals instruct the counter how many times to output a trigger at

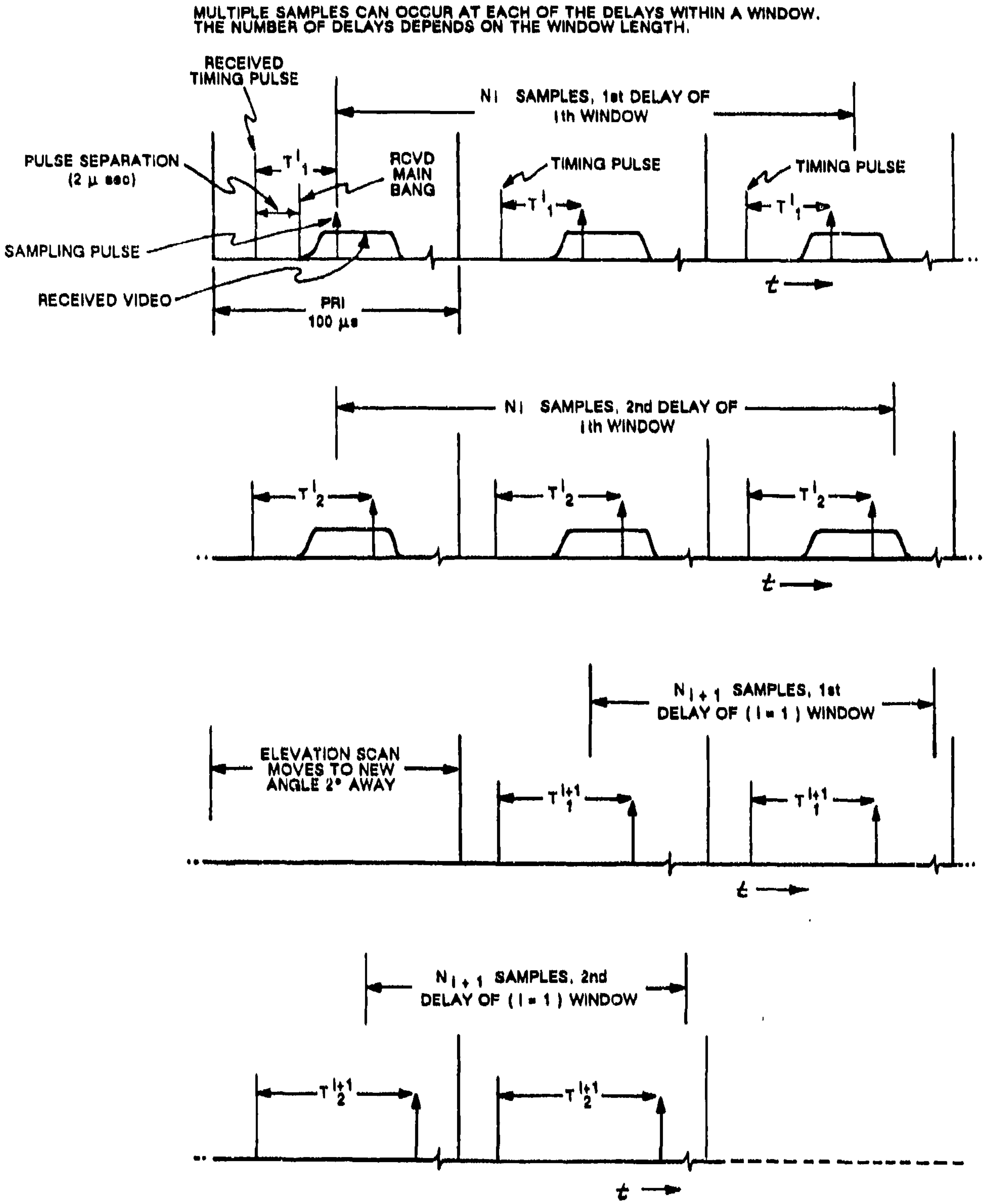
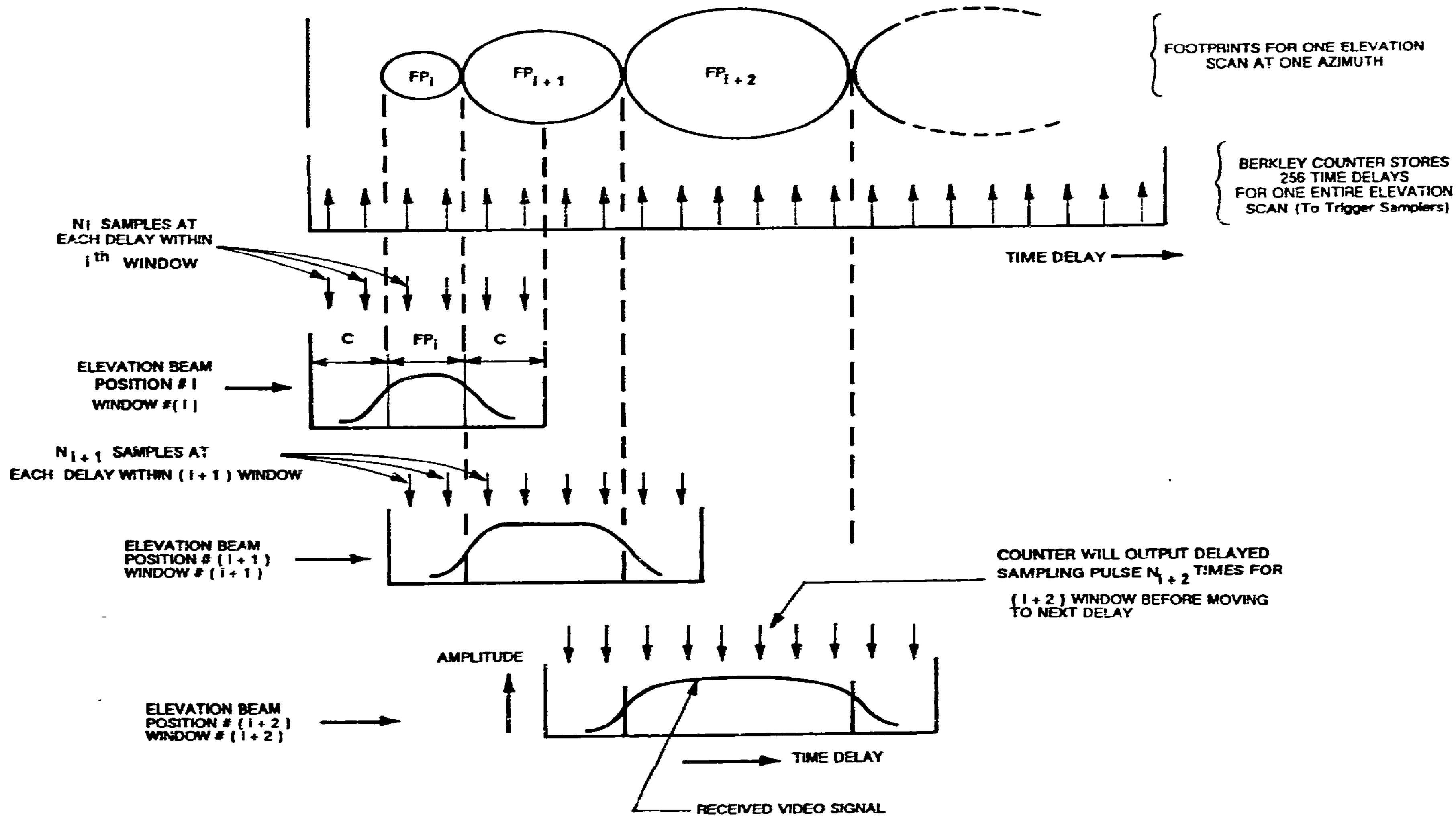


Figure 9 SKETCH OF SEQUENTIAL REAL-TIME SAMPLING OF TERRAIN SIGNALS



NOTES:
1. FP = Footprint
2. C = Cushion (Constant)
3. Multiple samples can occur at each delay, but within a window, the same number of samples is used at any given delay.
4. The number of samples at a given delay times the number of delays is limited to 200 within a window.

Figure 10 COMPOSITE SKETCH OF FOOTPRINTS, TIME DELAYS AND WINDOWS

a given delay before moving on to the next delay. The counter can store up to 256 delays which is sufficient for one entire elevation scan. When the antenna indexes in azimuth, new delays are loaded into the counter and the sampling process is repeated at the new azimuth. Figure 11 is a flow diagram of the signal sampling in the data collection procedure.

The magnitude of the time delays are an input parameter. Typically, the delays correspond to one, or more frequently, one-half of a pulsewidth. This results in two samples per pulse. It is possible to have a different pulsewidth for each azimuth but typically the pulsewidth is constant for an entire raster scan.

2.2 DATA COLLECTION PROCEDURE - DYNAMIC MODE

In the dynamic data collection mode, the transmitter is removed from the transmit helicopter and mounted underneath the fuselage of a fixed wing Piper AZTEC aircraft. The transmitter is at a fixed depression angle of 21 degrees, and the transmit aircraft flies toward the hovering receive helicopter. The receive antenna is fixed at a 10° depression angle and pointed in the direction of the approaching aircraft. The relative motion between the two platforms results in Doppler spreading of the forward scattered signals which is to be measured.

Figure 12 is a plan view of the "race track" geometry of the mission. Figure 13 is a profile view of the mission. Note that the transmitter is nominally at 1000' AGL while the receiver is at 5000' AGL. The MLS is located in one leg of the race track and, after overflying the MLS, both ships are located in space by the MLS and data collection is initiated. The collection of "gulps" of data, consisting of 750 pulses per gulp, starts well before the migrating transmit beam overlaps the stationary receive beam and continues until well after the transmit beam has passed over the receive beam. This assures that some data will be collected when the beams are overlapped. The gulps are taken every 1/2 second over a 2-minute data collection interval. Figure 14 is a time line illustrating the time interval of data collection referenced to the dynamic geometry.

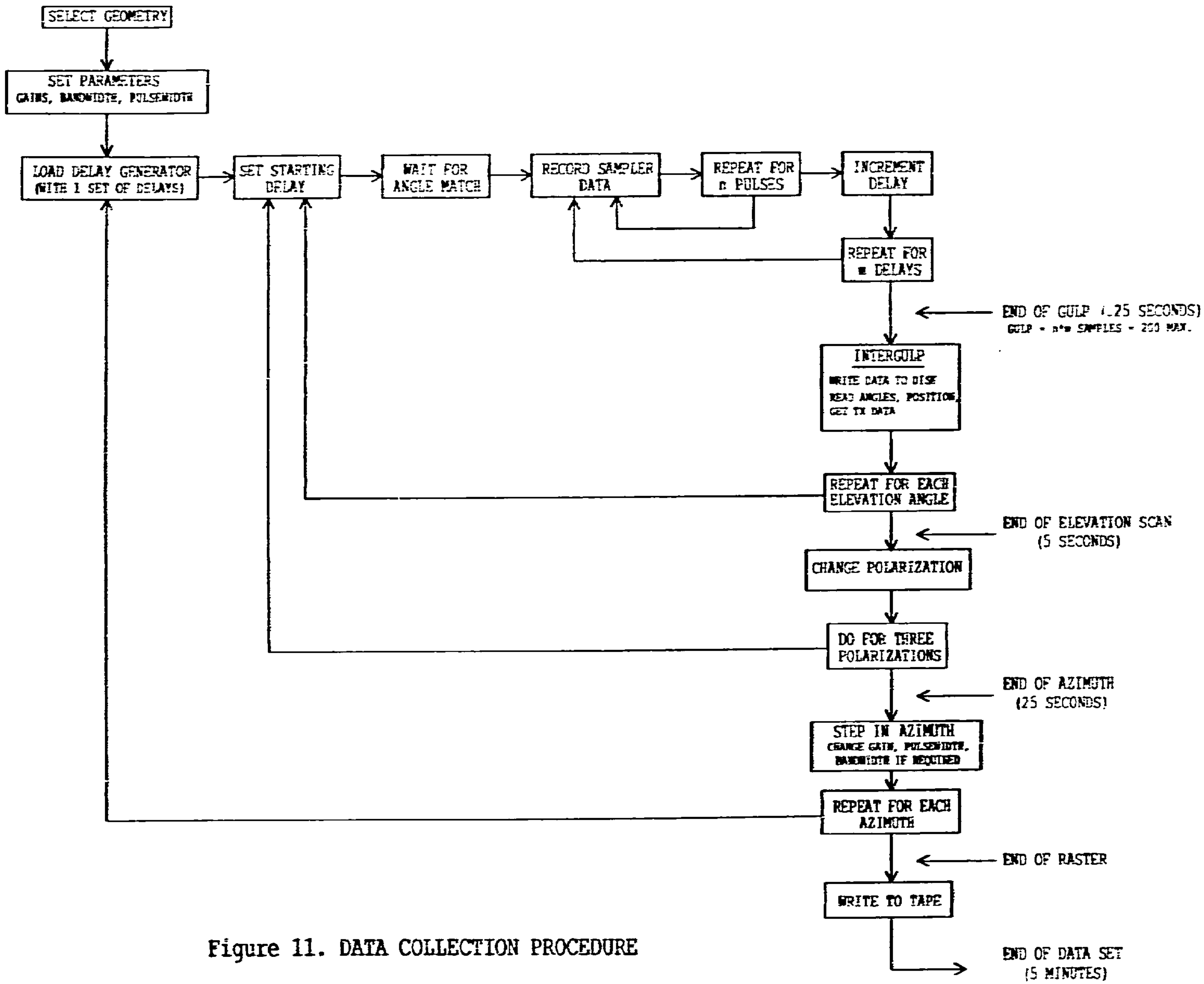


Figure 11. DATA COLLECTION PROCEDURE

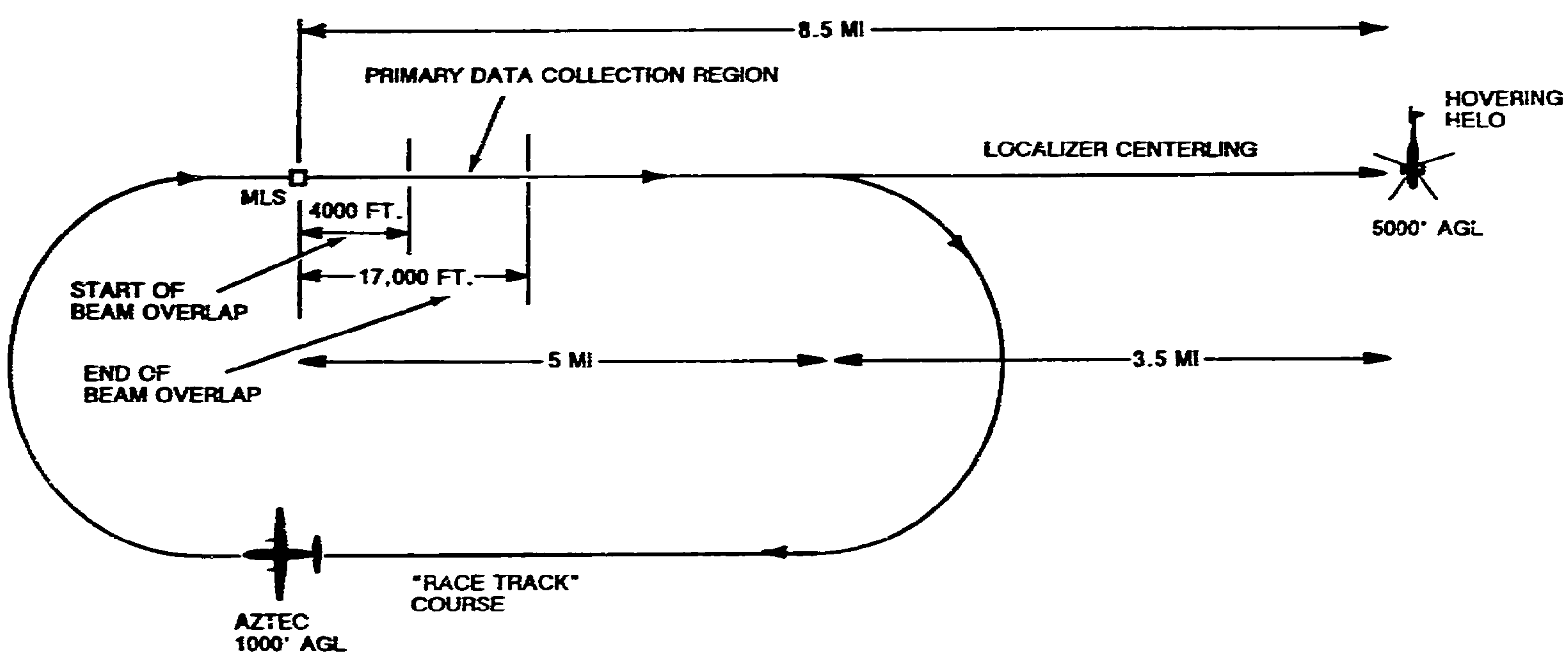


Figure 12. PLAN VIEW OF MISSION PROFILE FOR DYNAMIC TESTS

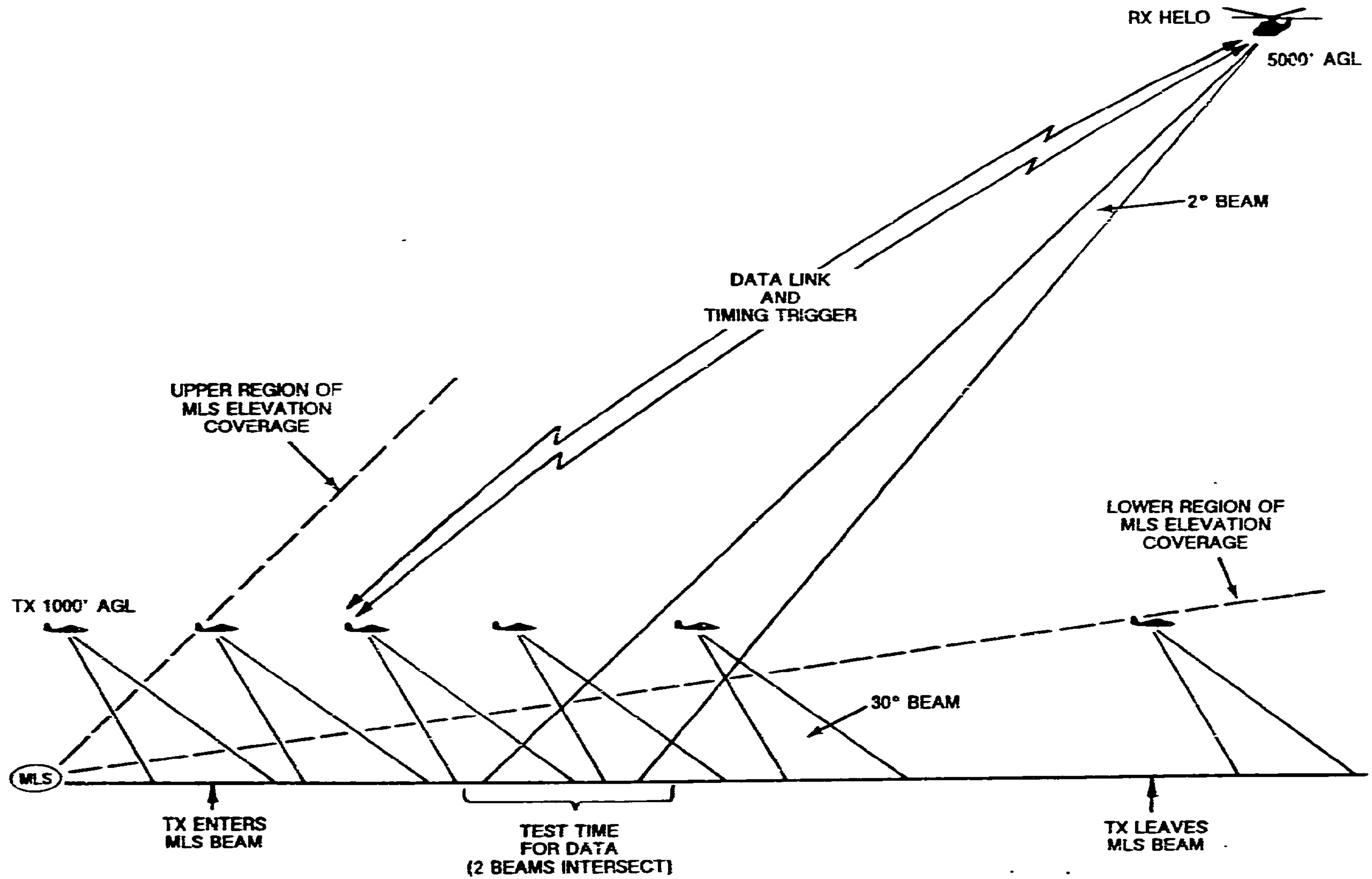
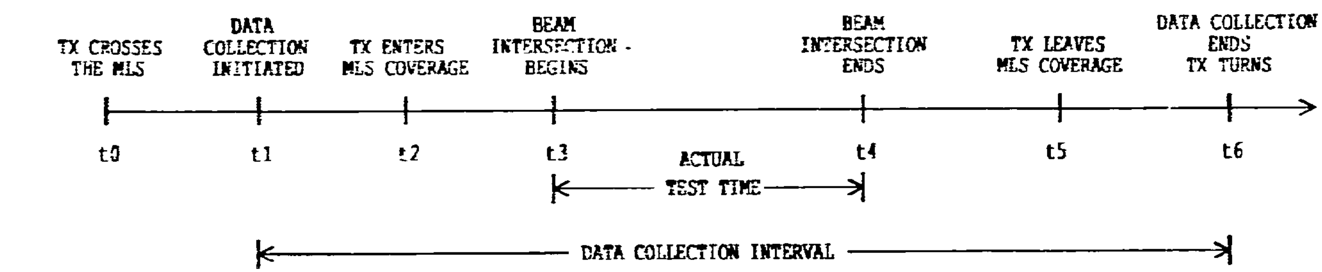


Figure 13. PROFILE VIEW OF DYNAMIC TESTS



APPROXIMATE EVENT TIMES

TX AIRSPEED	t1	t2	t3	t4	t5	t6
80 Knots	5 sec	26 sec	74 sec	91 sec	106 sec	120 sec
135 Knots	5 sec	16 sec	44 sec	54 sec	64 sec	120 sec
180 Knots	5 sec	12 sec	33 sec	41 sec	48 sec	120 sec

NOTES
1) DATA GULPS COLLECTED EVERY 0.5 SECOND
2) MINIMUM NUMBER OF GULPS COLLECTED DURING TEST TIME = 16 (180 Knot SPEED)
3) DATA COLLECTION STARTED AS SOON AS TX REPORTS OVER THE MLS AS A BENCHMARK
4) AS SOON AS DATA COLLECTION PROGRAM COMPLETED (APPROX. 2 MINUTES) TX TURNS

Figure 14. TIMELINE OF EVENTS IN THE DYNAMIC TEST SCENARIO

Each gulp of 750 pulses is collected at a specified time delay after direct. The first time delay is positioned between the timing trigger and the direct main pulse and provides for the sampling of noise. One gulp is taken at this delay. The next samples are taken at the delay corresponding to the direct time of arrival. Three gulps are taken at this delay. Four more time delays (after direct) are used to collect the terrain data, with 3 gulps being recorded at each. Thus, the first 6 time delays include 1 gulp for noise, 3 gulps for direct and 12 gulps for terrain. After these 16 gulps are completed (analogous to the 16 elevation angle "matches" in the static scenario), they are repeated (approximately 10 times during a data collection run). A sketch of the real-time sampling appears in Figure 15.

The specific time delays used are 160 nanoseconds for direct and 280, 400, 520 and 640 nanoseconds for terrain. The direct and terrain time delays were established by the geometry of the data collection scenario. The delays for the terrain data were computed to sample the specular and diffuse reflections during the overlap period.

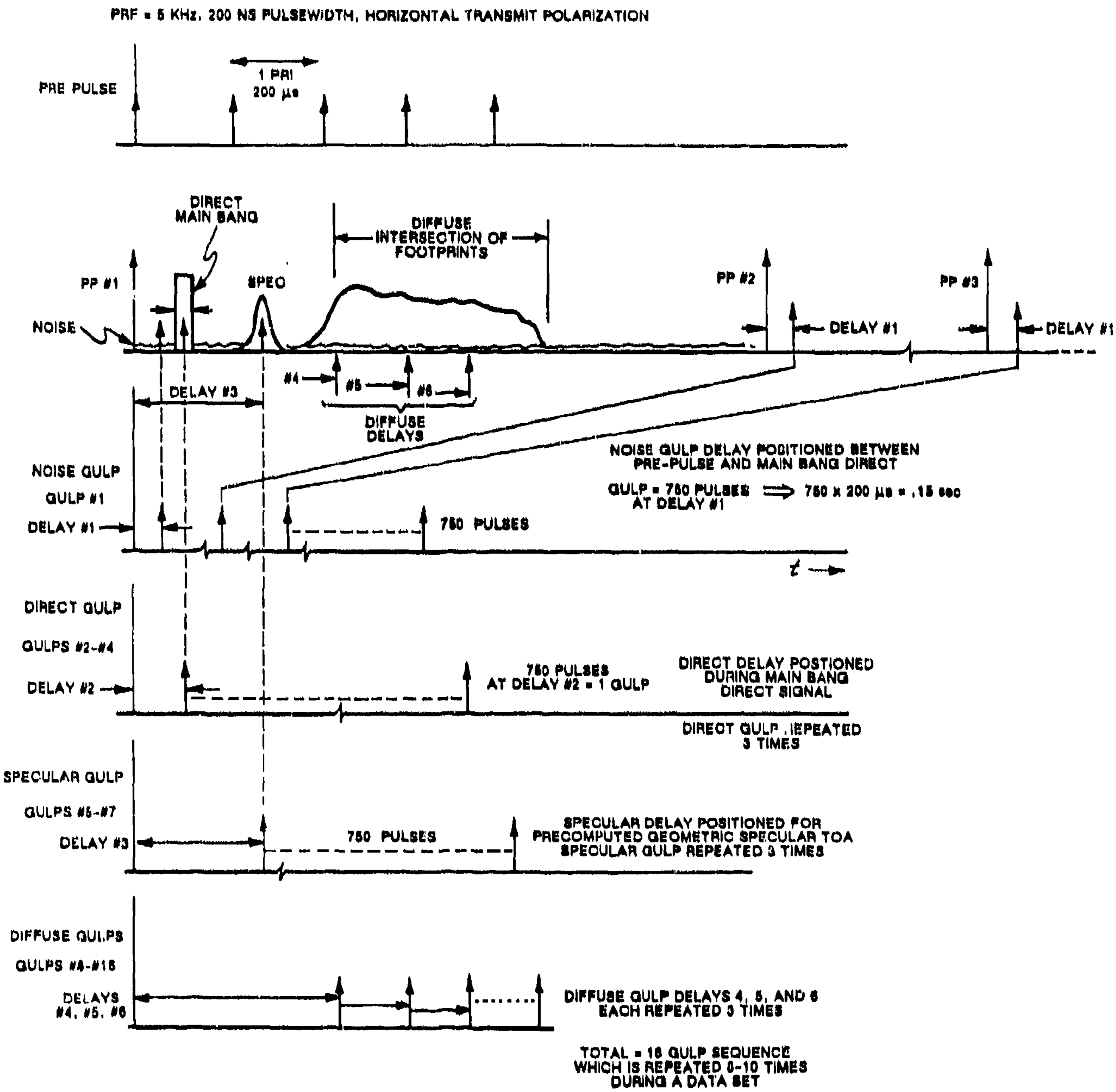


Figure 15 REALTIME SAMPLING IN DYNAMIC TESTS

Section 3
SYSTEM DESIGN

3.1 BACKGROUND

The overall purpose of the system design is to provide a radar and data collection system that will allow for in-the-field measurements of the bistatic scattering coefficient $\sigma°$ at X-band as a function of polarization and angle triad (incidence, reflection, and out-of-plane angles). To measure $\sigma°$, the system must generate and record radar signals bounced off the terrain and provide means for defining the other radar range equation components. Also, in order to associate computed $\sigma°$'s with the angle triads, a means of defining the geometry must be developed that will include not only radar platform locations but also precise pointing angles of the radar beams in unison with the radar data being recorded. Further, the system must be efficient in providing multiple measurements for statistical averaging of the data.

3.2 DESIGN PHILOSOPHY

The basic design philosophy is to have a central control point for the entire data collection process. A powerful computer is needed that will perform multiple tasks in real time with several independent processes running in unison. The Masscomp MC 500 was chosen based on its multi-tasking/multi-processor architecture and speed. This computer is responsible for controlling the radar parameters (pulsewidth, bandwidth, gain, and polarization), and is the central data recording facility for all data, and also acts as the master controller for the rest of the system. Other processors are slaved to the MC 500 and perform functions such as antenna control, data link operation between aircraft, generation of overall system timing, and provisions for position information and station keeping guidance for the pilots in real time. Since the majority of the data collection is done on the receive side, it was logical to put the

MC 500 in that aircraft to minimize data link transmissions. Figure 16 shows the Terrain Measurements system functional block diagram including data recording and system control.

3.2.1 Radar Parameters

Computations to find a bistatic scattering coefficient use the radar range equation

$$P_R = \frac{P_T \, G_T \, G_R \lambda^2 \, \sigma° A}{(4\pi)^3 \, R_{TG}^2 \, R_{GR}^2}$$

In order to find $\sigma°$, the other components of this equation must be determined. P_R is the power level received at the receive antenna terminals from the bounced radar signals and is computed using the measured voltages out of the receiver along with recorded gain settings. P_T is the transmitted power level and is a constant that is updated if required using calibration values. G_T and G_R are the gains of the transmit and receive antennas respectively taken from antenna pattern measurements. The wavelength (λ) is for the radar frequency (9.8 GHz). The area A is computed using the intersection of the receive beam footprint with the ground. The narrow 2 degree beam for the receiver was selected in part to constrain the size of the receive area. R_{TG} and R_{GR} are the ranges from the transmitter to the ground and from the ground to the receiver respectively and are computed using the relative position information of the platforms recorded in real time.

The system must provide sum, azimuth difference, and elevation difference signals in order to implement a monopulse separation algorithm to separate specular and diffuse components in the received signals.

In order to provide a $\sigma°$ as a function of polarization, the transmit antenna selects between vertical, horizontal, or right

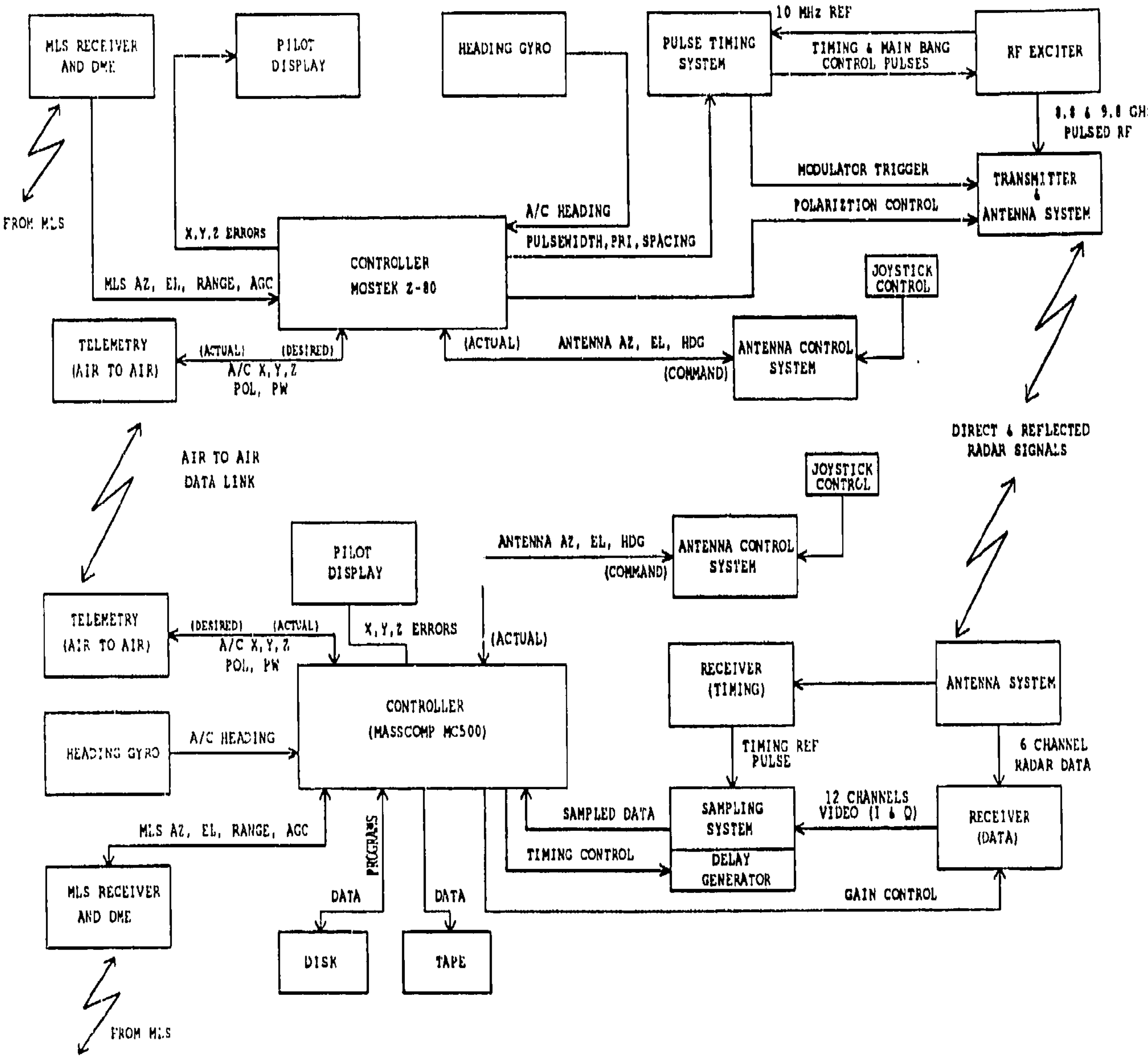


Figure 16. Terrain Measurement System Functional Block Diagram

hand circular polarization. The receive antenna provides simultaneous co- and cross polarization selectable between either linear or circular. Receiving simultaneous polarization allows for observations of depolarization effects due to the terrain.

Other parameters such as pulsewidth, bandwidth, and gain control were established as a result of a signal strength analysis.

3.2.2 Geometry Determination

In order to associate a computed σ° with the appropriate angle triad (incidence, reflection, and out-of-plane angles), the entire geometry at the time the radar data was collected must be known. Referring to Figure 3 in Section 2.1.2, it is evident that the required parameters are: 1) positions of both platforms (aircraft) in space, 2) pointing angles of the receive antenna in azimuth and elevation, and 3) the relative height and slope of the terrain at the point of incidence/reflection with respect to the radar platforms.

Platform positions are found using a portable microwave landing system (MLS) which provides the azimuth, elevation, and range to each aircraft referenced to the MLS ground position. See Section 7 for a more complete discussion on the MLS.

Pointing angles of the receive antenna are measured and recorded using synchro readouts on the antenna mount in real time during data collection. (See Section 6 for a more complete discussion of the antenna positioner and stabilization systems.) Tracing a ray to the ground from the receive antenna boresight defines the ground point that is associated with the radar data. The resultant incidence angle from the transmitter is found by tracing a ray from this ground point back to the transmitter position in space. Precise knowledge of the transmitter boresight pointing angles is not required since it is a wide illumination beam. The incidence angle may be from any ray within the main beam.

Terrain heights relative to the radar platform positions must be found using some form of terrain topographic map.

3.2.3 Statistical Averaging

The computed σ°'s associated with angle triads will be collected over several types of terrain. It is important to collect several samples for each terrain type. In this way an average σ° as a function of polarization and angle triad associated with a particular terrain type can be found. Averaging over multiple samples will eliminate discrete radar returns for a unique terrain sample from producing misleading results. For this reason, a means of collecting data over different physical patches of a homogeneous terrain type is needed. The method of using two hovering helicopters as radar platforms fits this need quite well since the hover positions can be readily changed to not only provide different nominal geometries but also to provide different physical locations for collecting data samples at the same nominal geometry.

3.3 CONSTRAINTS

Constraints on the system can be divided into three categories: 1) constraints associated with equipment performance, 2) constraints due to the selection of the two UH-1's as platforms, and 3) constraints due to the positioning system (MLS) which defines the nominal geometry configuration.

3.3.1 Equipment Constraints

Limitations of the equipment define the overall system performance during the data collection time. Some of the most important of which include the following.

Environmental: Most of the equipment on board the aircraft is commercial grade with a specified operating temperature range typical 0 to 50 degrees C. A nine-track magnetic tape used as a backup storage medium for all data collection has a more rigid temperature specification (5 to 30 degrees C) but is nonessential to the data collection scenario. On-board heaters allow for operation when outside temperatures are lower than 0°C. Hover requirements limit operation at outside air temperatures that fall below the equipment limitations. The most constraining environmental aspect of the equipment is by far the fact that some equipment is exposed to the outside environment and therefore a stipulation that the equipment not be unnecessarily exposed to precipitation (rain or snow) is required.

Delay Generator: The Berkley 7085 delay generator used to set the sample times of the radar data can be preloaded with up to 256 discrete delay settings, each a fixed (sample) increment apart, in a memory buffer. Due to the time required, resetting the memory with new values can only be done between successive scans of the receive antenna. Therefore, each antenna scan is limited to a finite number of TOA delays which can be sampled. (See Section 2.1.4 for a more complete description of data collection and sampling methodology.)

Masscomp Computer: Several limitations associated with data collection are the result of 1) maximum data transfer rates between the data acquisition processor (DACP) and the main memory of the data disk, 2) time required to readdress buffers and do buffer swapping, 3) system interrupt latency limits, 4) interactions with the operating system in real time, and 5) total disk space available. The first four limitations translate to maximum scan rates of the receive antenna to allow enough time between radar data collection "gulps" (see Section 2.1.4 for definition of a "gulp") to ensure that buffers are not over written or control messages lost due to denial of access to the buss at the required time. The present system is restricted to about 300 msec between data gulps. This translates to a 6-degrees/sec scan rate during regular data collection where data are taken every 2 degrees, or 3 degrees/sec during mini scan or direct beam data sets which collect data in 1 degree increments. In order to keep block sizes of data to a manageable size for the buffer swapping, the present limitations are 1) each data gulp may consist of 200 delay-samples (number of delays for the gulp times the number of pulse-to-pulse samples per delay), 2) the number of gulps per antenna elevation scan is 16 maximum. The available disk space (see item 5 above) refers to the maximum amount of data that can be collected in real time before the data must be backed up on magnetic tape and the disk erased. A separate 85 megabyte hard disk is designated for data storage only and will allow for up to 20 data sets. Typical data collection flights yield 6-10 data sets.

3.3.2 Installation Constraints

The selection of the UH-1 helicopter as a radar platform carries with it a unique set of restrictions which included the following. (See Section 3.6 for a more complete description of the installations.)

Weight and Balance: All project related equipment must fit within the cargo area of the helicopter in an approved installation that meets requirements for weight and balance as well as safety. Any modifications to the system require approval and inspection by the responsible agency. The maximum gross weight of the project related equipment (including the operator) must be within the available limits for gross weight of the aircraft after the weight of the aircraft, full load of fuel, and two pilot's weight have been factored out. The receive helicopter, with the large amount of weight in equipment it carries, is close to the limit of 2200 lbs. allowing for the operator and only one other passenger (observer or crew chief). The transmit helicopter on the other hand is well within the limits and can carry up to 5 passengers. (The Aztec carrying the transmit equipment allows for only the operator and two pilots.)

Vibration: The vibration environment in the UH-1 is especially critical in the vertical direction with high amplitudes and low frequencies. A special series of vibration isolators and shock mounts were used for all panels installed in the equipment racks. In addition, the Masscomp computer in the receive helicopter was given special attention. All commercial grade equipment was modified to be flight worthy.

Antenna scan angles: The installation in the helicopters restricts the scan angles of both the transmit and receive antennas. As shown in Table 2 there are two types of limits placed on the antenna pointing angles. Software limits are driven by the electromagnetic interference of the aircraft frame with the radar signals. Mechanical limits are to protect the equipment from damage through physical contact with the airframe. The transmit antenna is restricted to 35 degrees downlook, 10 degrees uplook, and +/- 45 degrees in azimuth. The receive antenna is restricted to 30 degrees downlook, 6 degrees uplook, and +/- 32 degrees in azimuth. In both cases the restricting factor in azimuth is the shadowing effect and/or physical interference with the helicopter structure. Azimuth is limited by the aft bulkhead and the forward false wall installed in each aircraft. Likewise, in both cases the downlook limitation is a result of interference with the radar beams by the floor of the cargo compartment. The uplook limitation is a result of mechanical interference with the antenna yoke assemblies.

Table 2 ANTENNA POINTING ANGLE LIMITS (DEGREES)

	Transmit	Receive
Azimuth Limits (Software)	±45	±30
Azimuth Limits (Mechanical)	±60	±35
Elevation Limits (Software)	+10 to -35	+6 to -32
Elevation Limits (Mechanical)	+15 to -60	+7 to -35
Pitch	±15	±15
Roll	±15	±10

Aircraft maneuvering: Each of the UH-1 helicopters has an operating envelope that has been defined as a result of safety test flights by the Army after the installation were complete and cannot be compromised from the safety aspect. Restrictions include the following. With a zero forward wind speed (i.e., hover) the aircraft must be at least 1000 feet above ground level. This applies to both aircraft. Maximum forward airspeeds were also defined for the receive aircraft because of the 4-foot dish antenna in the down wash that causes interference with normal aircraft aerodynamics as well as stress on the stabilization system. These include a maximum forward airspeed not to exceed 30 knots with the receive antenna free to scan (i.e., in the data collection configuration) and a 60-knot limitation when the receive antenna is pinned with support bars in the ferry configuration. No forward airspeed restrictions exist for the cross-country transport configuration since in this case the antenna and stabilization system are removed. No airspeed restrictions exist for the transmit aircraft since the antenna and stabilizer do not protrude from the cargo area. Additional limitations on aircraft usage include day-time visual flight rules (VFR), a maximum of two missions per day, and a maximum of 90 minutes per mission. Ferry time to and from the test area would be excluded from the mission time.

Logistics: Using the UH-1 helicopters (or any other aircraft) requires that the site selected for testing not only represent the terrain type of interest but also provide certain logistic support. Hangar space must be available within a reasonable distance from the test area for efficient daily operation as well as protection from the elements for the equipment. Fuel for the aircraft, both JETA and 100 LL (for the Aztec) must be readily available and if possible at or near the actual test area to conserve flight time. In addition the hangar must provide a means to supply ground power to the aircraft during set up, calibrations, and on-site data reduction. This could be either in the form of 28 VDC directly to the aircraft or 208 V 3-phase which powers a rectifier unit that is part of the support equipment furnished by AERA with the aircraft.

3.3.3 MLS Positioning Constraints

The angular coverage of the MLS system used to position the aircraft, in unison with the helicopter minimum hover altitude restriction, constrains the geometries over which data collection can be performed (especially for the low grazing angles) and also defines requirements on the size of the test area. For instance, for a nominal 4 degree specular geometry and a minimum 1000 feet AGL hover limitation, the two aircraft must be on the order of 28,600 feet apart. (This represents about 165 dB range path loss of the radar signal.) To stay within the +/- 55 degrees of usable azimuth coverage of the MLS localizer beam the aircraft must be on the order of 10,000 feet from the MLS ground station location. This means, in order to accommodate any wind direction, the terrain type must be homogeneous over an area of at least a 2-mile radius. Further, at a distance of 10,000 feet from the MLS and at a hover altitude of 1000 feet, the apparent elevation angle of the MLS glide slope will be less than 6 degrees. This may be a factor for maintaining line of site between the aircraft and the MLS ground station especially at sites with tree cover. Likewise, for a nominal specular geometry of 2 degrees the glide slope elevation angle to the MLS would be less than 3 degrees, a region of coverage that provides inconsistent data.

3.4 OVERALL BLOCK DIAGRAM AND SYSTEM DESCRIPTION

3.4.1 Transmit System

The transmit system, as shown in Figure 17, consists of a central controller with associated peripheral equipment modules. This controller acts as a stand alone computer to initialize the system and also to perform diagnostics, readiness tests, and calibrations. During the test scenario, the controller acts as a slave unit to the master controller (the Masscomp MC500) in the receive helicopter.

3.4.1.1 Controller. The controller consists of a Mostek Z-80 computer using an 8-inch floppy disk drive to load in realtime and diagnostic software programs. Additional boards which were added to expand the basic capability include a floating point processor board for fast computation of position information as it is received from the MLS receiver, a pulse forming board and a counter/timer board. The pulse board used in conjunction with the counter/timer board: 1) provides the pre-pulse and main-bang ECL driver pulses to the exciter RF switches, 2) sets the pre-pulse interval (PPI) or the time between pre-pulse and main-bang, 3) sets the pulse repetition interval (PRI), and 4) provides the trigger pulse to the transmitter TWT which turns the amplifier on for the pulsed RF signal. Input from a 10-MHz rubidium source provides for a very accurate external clock signal to the counter/timer board which allows for precise pulse shapes and spacings down to the nanosecond.

A transmitter controller program {TRANS} allows an operator using specially defined control functions to interactively control portions of the transmitter system. This program is used to check out the system as part of readiness tests and calibrations and also to initialize the system for data collection. During the data collection process, the program allows

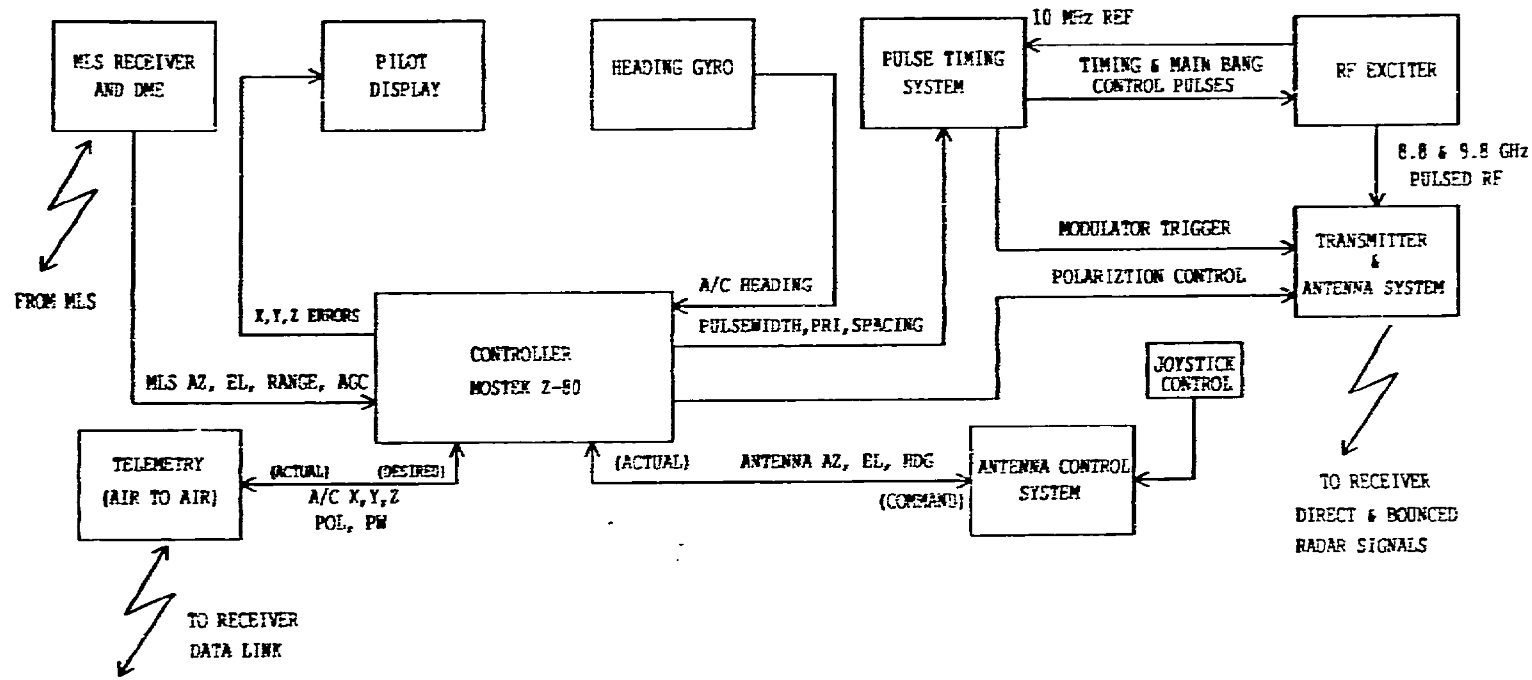


Figure 17. Transmit System Functional Block Diagram

for commands from the receive aircraft central processor controller (Masscomp MC-500) to control transmit system parameters in real time via the data link. Figure 18 is the data and control flow diagram for the transmit system.

3.4.1.2 Transmitter. The transmitter, including both the exciter unit and the TWT are controlled by the Mostek system. The exciter unit produces the pulsed RF signals for both the timing signal and the main radar signal. These signals are then amplified by the TWT and sent to the transmitting antenna. Inputs from the controller include ECL driver pulses for two RF switches which produce the pulsed RF for the timing signal and the main transmit signal and the trigger pulse for the TWT. The exciter panel provides the controller with the 10-MHz reference signal. See Section 4.1 for a more complete description of the transmitter.

3.4.1.3 Antenna System. The controller allows for both manual and computer control of the antenna. These controls include selection of the transmit polarization and antenna pointing angles via the antenna control unit. The transmit antenna may be positioned to discrete azimuth and elevation angles. The antenna does not scan.

Polarization selection may be done either manually through the Mostek terminal using special control characters or automatically by the Masscomp master controller via the data link. Polarization may be selected as horizontal, vertical, right-hand circular or left-hand circular.

The antenna control unit may be operated in two modes, true and relative. These two modes deal with different requirements for azimuth angle control. Elevation angles in both modes are the same and are relative to horizontal. Initialization of the system by default sets the elevation to 0 degrees. Inputs to the antenna controller are done manually via either the keyboard for

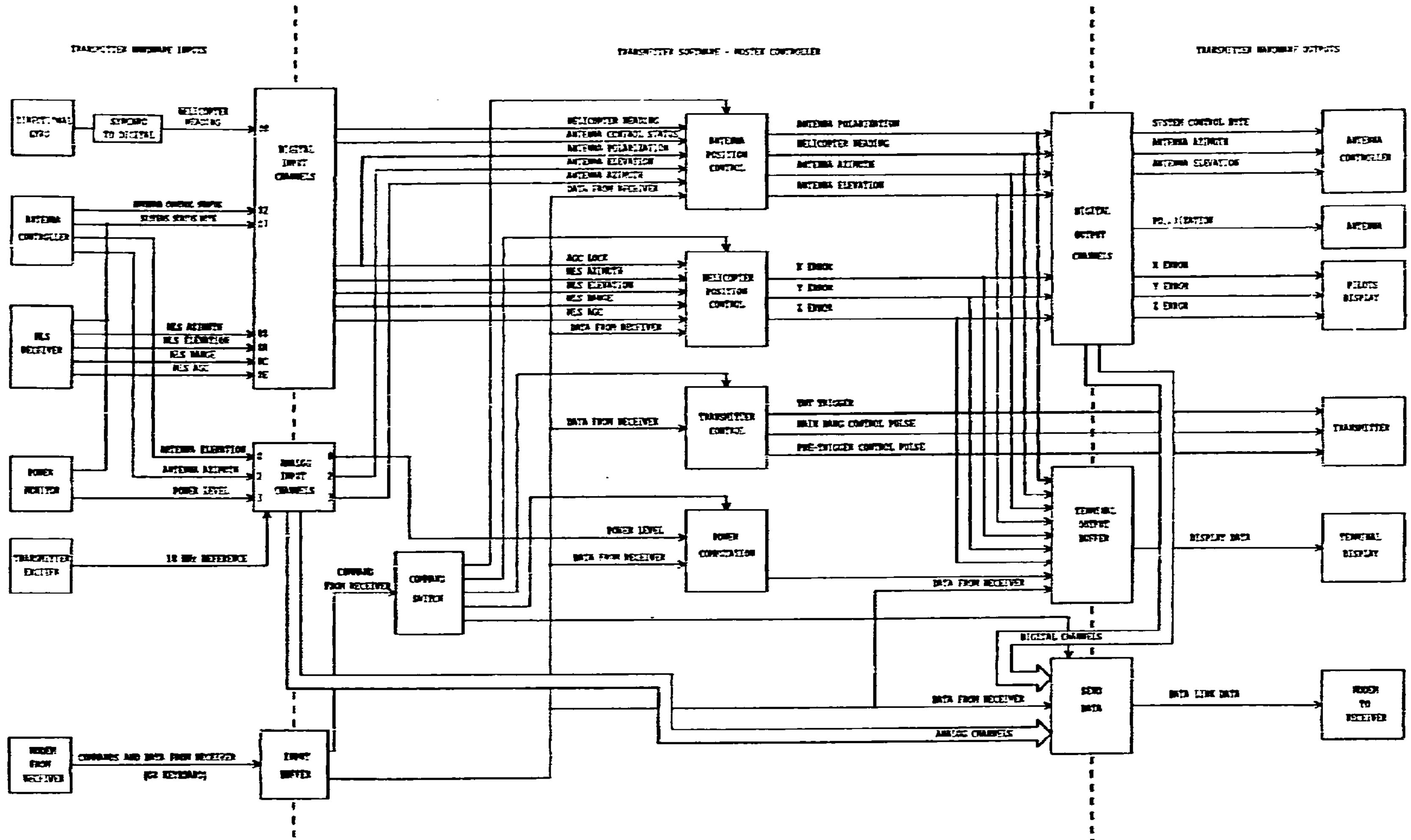


Figure 18. Transmit System Data and Control Diagram

discrete angle inputs or the joystick which allows for simultaneous azimuth and elevation continuous movement.

In relative mode, the pointing angle in azimuth is with respect to a position orthogonal to the aircraft centerline. In this mode, the yaw motion of the aircraft is not corrected for so that as the aircraft changes heading the antenna follows. Upon initialization of the transmit system, the antenna controller unit is set to this mode and a value of 0 degrees the default. This allows for the transmit aircraft to maneuver to position without pinning the antenna against one of the azimuth stops.

In true mode the azimuth angle is with respect to true north. In true mode the inputs to the controller include the magnetic heading of the aircraft from the heading gyro compass and a manually input compass correction value based on the geographical location. These inputs are used to compute in real time the true north relative pointing angle of the antenna and allows for corrections for yaw motion of the aircraft. This mode is used during data collection so that as the aircraft yaws the antenna remains pointed in a fixed direction with respect to true north.

Correction of the antenna pointing angles for other aircraft motions (pitch and roll) is provided by the antenna stabilization system (see Section 6.2).

3.4.1.4 Aircraft Positioning System. The transmit aircraft is positioned in space during data collection with the use of a Microwave Landing System (see Section 7.0). The aircraft receives signals from the ground station via the airborne antenna and receiver and passes azimuth, elevation and range information to the controller. The {TRANS} program computes in real time the aircraft's spatial position in x, y, and z coordinates, computes the position deviation from desired values, translates those errors to the aircraft coordinate system, and provides error signals to the pilot display for station keeping.

Desired position in x, y, and z coordinates are manually input by the transmit operator in the {TRANS} control program for the pre-planned desired geometry for data collection. The operator also inputs the MLS centerline referenced to true north so that the program can properly transform the desired corrective actions for the pilot referenced to his aircraft heading.

The pilot display consists of "fly-to" indicators for forward-back, left-right, and up-down. (Fly-to means that the pilot flies in the direction that is indicated.) This display is provided to both the pilot and the co-pilot so that the flight crew can easily share the work load. The pilot display has two modes of operation, computer and MLS direct. In MLS direct the indicator acts as a standard MLS indicator showing deviation from the localizer centerline and the glideslope angle selected. In computer mode the indicator provides the corrective actions required to maintain a position in space that is not necessarily on the localizer centerline. In computer mode, the indicator has two scales: coarse and fine. The full scale values of this indicator are coarse scale +/- 500 feet, fine scale +/- 100 feet.

During dynamic tests when the transmitter equipment is installed in the Aztec fixed wing aircraft the pilot indicator is used in MLS direct. The Aztec pilots fly a course that tracks the MLS localizer centerline and maintains altitude using the aircraft's pressure altimeter.

3.4.1.5 Telemetry. Digital communication between the two aircraft is provided by means of a 1200-Baud data link. The transmitter/receiver sets are matched so that one aircraft transmits on frequency 1 and receives on frequency 2 and vice versa for the other aircraft. This provides for a full duplex system using a common antenna. The frequency separation and filtering of the received signal assures that the transmitted signal does not interfere with the co-located receiver. The antenna is a log periodic with wide angular coverage to provide continuous link operation over long distances and position variations. The types of data that are sent from the transmitter aircraft to the receiver aircraft over this link include pulsewidth polarization, and MLS position data. The transmit aircraft receives from the receiver master controller command information which includes changes in polarization and pulsewidth and requests for position data. See Section 4.5 for a more complete description of the data link.

3.4.1.6 Video/Voice Recorder. During data collection a video picture of the area on the ground roughly the same as that which is illuminated by the transmitting antenna is recorded. This is done using a video camera mounted just below the transmitting antenna which is part of the antenna assembly and also stabilized for aircraft motion. This camera has an electronic zoom lens that is set such that the field of view of the camera is about the same as the 3-dB beamwidth of the transmitting antenna. The video picture is displayed in real time to a video monitor in the aircraft so that the operator can observe the area being illuminated by the radar. The video picture is also recorded for future use. Audio inputs to the recorder include all voice transmissions; air-to-air, air-to-ground, and intercom conversation between crew members within the aircraft.

3.4.1.7 Diagnostics and Readiness Tests. The transmit system contains elements that are used both pre-test and during test that allow the operator to observe the system performance and verify that it is operational.

A separate diagnostic program reads the voltage sense lines of the various power supplies within the aircraft and posts them to the terminal screen for the operator. This allows for a quick check of the status of the power supplies.

The screen display from the {TRANS} program presents the operator with various information on the transmitter and other system parameters. These include:

Pre-pulse to main bang spacing
Pulse repetition interval
Pulsewidth (desired and actual)
Polarization (desired and actual)
MLS x,y,z (desired and actual)
MLS centerline
Compass correction
Antenna angles (az and el) (desired and actual)
Transmitter power

The transmitter power presented on the screen is a result of the digital reading on a power monitor in the transmitter circuitry.

The airborne elements of the MLS system can be quickly checked using a BIT test on the receiver unit. The results will be specific values presented on the screen display and specific positions of the needles on the pilot's display.

A detected sample of the transmitted pulse is presented to an on-board oscilloscope which allows the operator to view the transmitted pulse and verify its pulsewidth.

3.4.2 Receive System

The receive system, as shown in Figure 19, consists of a central controller that provides for all the real-time experiment control as well as pre-test set up and post-test data reduction. During a data collection session the system acts as the master controller for the transmit system by establishing a communication link to the transmitter controller.

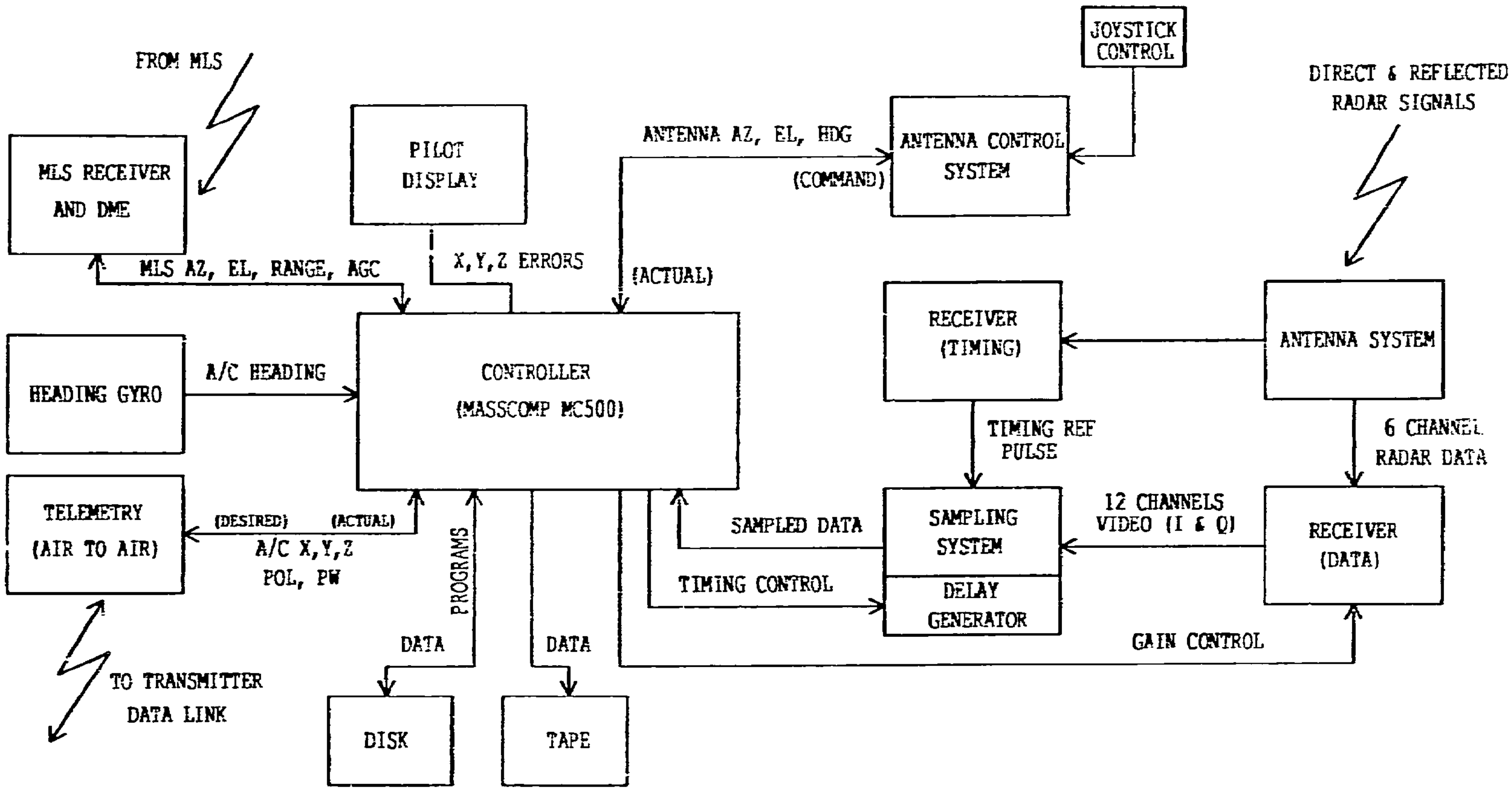


Figure 19. Receive System Functional Block Diagram

3.4.2.1 Masscomp MC500 Controller. The Masscomp MÇ500 acts as the central control point for all equipment within the receive helicopter. It also provides control for some of the transmitter parameters. It performs all of the experiment control functions from pre-test, to real-time control and data acquisition, to post-test data reduction.

Pre-test experiment control consists of determining, prior to testing, the parameters to be used. Some of these parameters are manually selectable and some are predetermined based on the experiment plan. For instance, the pulsewidth for a given geometry may be manually set to a fixed value for the entire data set whereas the polarization sequence is preset in software. The pre-test software which predetermines the angles, sampling times, number of pulses for integration, etc. is described in more detail in Section 8.

Real-time experiment control consists of control messages being sent to various peripheral equipment from the central processor. These control messages are summarized in the data and control diagram shown in Figure 20. Several types of buses are used to route the data and control messages. In addition to the internal bus system of the Masscomp, a general purpose digital I/O bus (DIOB) from the Masscomp digital I/O port provides for most control and data acquisition flow through custom designed interfaces. Also, direct control of standardized equipment (like the delay generator and antenna control unit) is handled through the Masscomp GPIB (IEEE 488) general purpose interface bus.

During the data collection process, all data for the data reduction algorithms are recorded by the Masscomp. This process is handled by the DACP (data acquisition co-processor). The data are recorded into data files, one per data set, each with its own unique identifier. The data in this file include the following:

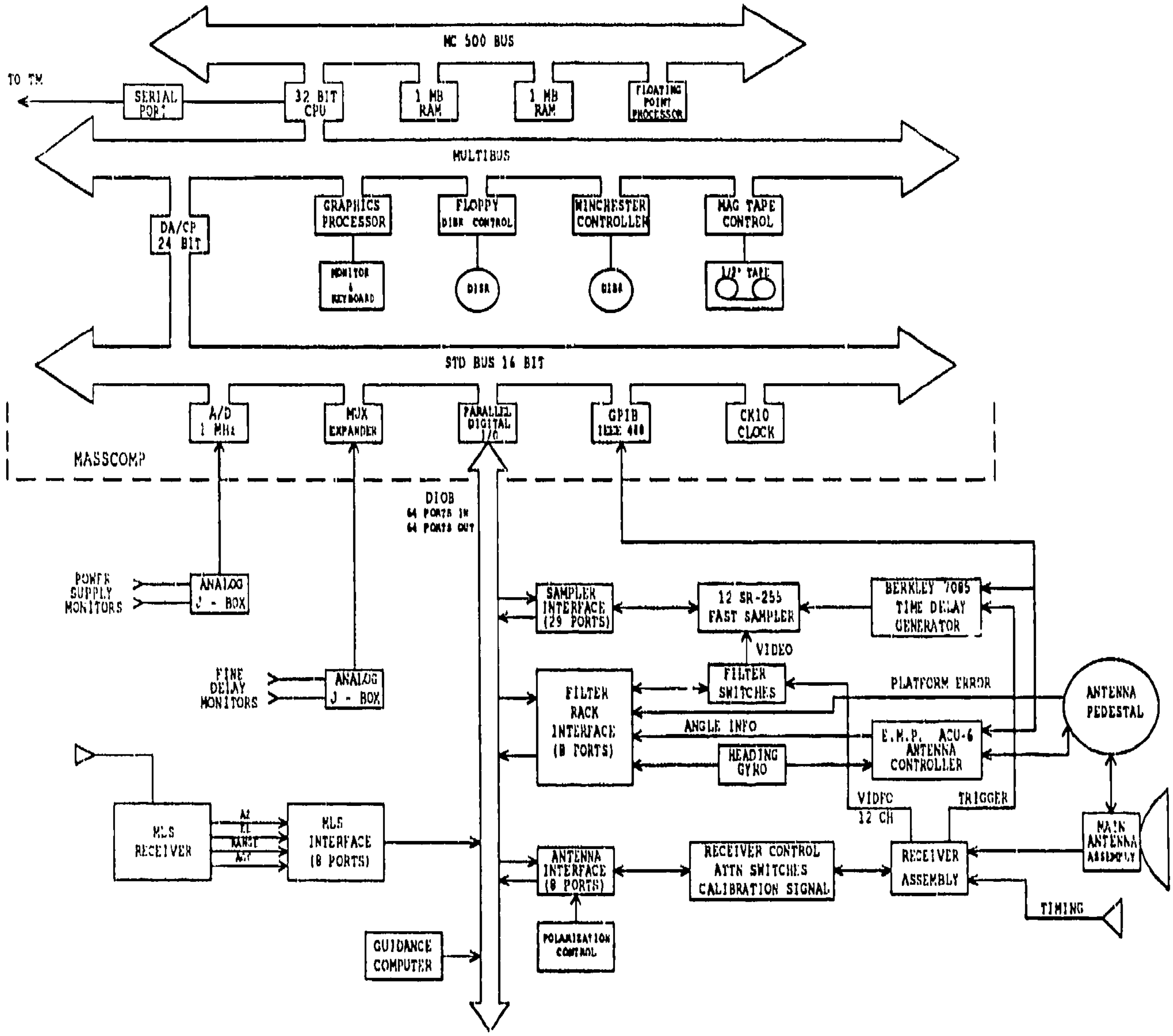


Figure 20. Receive System Data and Control Diagram

File header containing site name, date, time
Radar video data (12 channels from the samplers)
Antenna angles (az and el from the antenna mount)
Antenna pitch/roll errors (gyro deviations)
Position of RX helo (az, el, range from MLS)
Position of TX helo (az, el, range from MLS)
Pulsewidth
TX and RX polarization
Gain setting
Filter selection

The maximum transfer rate of the DACP to the system's main memory is reported by Masscomp to be 2 megabytes per second. In order to maximize this rate custom DACP microcode with a specialized handler was developed. This microcode consists of a 290-bit slice implementation which runs at 8 MIPS (million instructions per second).

Since all the data from a data set does not fit in the CPU main memory, the limitation of the data collection process is the transfer rate to the hard disk. During the development of the DACP microcode, a series of tests were conducted that showed the best sustained I/O rate was about 35,000 samples per second. Experiment requirements and data rate limitations, along with an effort to keep data sets to a reasonable size, led to a burst data collection technique at specific angles (or "gulps" of data) rather than continuous data collection.

The data that are collected are written directly to the RAM of the CPU in block sizes large enough to accommodate the maximum amount of data recorded during one elevation scan of the antenna. During the turn around time between successive elevation scans new polarization and pulsewidth parameters may be sent via the data link to the transmit system. Also during this time the most recent block of data is written to the hard disk designated for data recording. At the end of the data collection session back-ups of the data (hard) disk are made by transferring the data to 9-track magnetic tapes. The data disk can then be erased and made ready for the next data collection session.

The terminal for operator interface provides the operator with real-time on-screen status reports of the system operation. This includes displaying the radar parameters, antenna angles, and position data. In this manner the operator may monitor the data collection processes being performed. A detailed description of the real-time experiment control and data acquisition software can be found in Section 8.

3.4.2.2 Receiver. The receiver itself is discussed in detail in Section 4.2. Computer control of the receiver parameters such as gain and bandwidth are initialized by the Masscomp controller. The initial gain settings may be changed by the operator prior to the start of the data set. Otherwise there is no real-time interaction with the receiver during the actual data collection. Injection of the calibration signal, change of gain as a function of the azimuth angle, and commands for changes in the pulsewidth and polarization are performed by the Masscomp controller as per the pre-test setup parameters. This allows for a minimal amount of operator interaction, and therefore the possible introduction of human error, during the data collection sequence.

3.4.2.3 Central Timing. The timing for the data collection process is based on the timing signal received direct from the transmitter. A trigger timing pulse is transmitted at a precise time (2 us) before the main radar pulse. This trigger pulse is received at the receiver and sets the time zero reference for the delay generator. The detected video trigger pulse from the timing receiver (see Section 4.3) is fed to the delay generator. The delay generator, programmed with precomputed time delay settings dependent on the test scenario, provides the samplers with their trigger pulses for data recording via a timing distribution panel.

This distribution panel takes the TTL output pulse from the delay generator and feeds it into a series of line drivers which provide the 50 ohm compatible trigger pulses for the sampler inputs. Each of the individual trigger lines is the same length so as not to introduce timing errors between the individual sampler triggers.

3.4.2.4 Antenna Controller. The antenna control unit (ACU-6) is a commercially purchased unit from E.M.P. by the stabilization system subcontractor D2C. It allows for local control of the antenna position and scan pattern in an off-line check out and calibration mode through both the front panel controls as well as an external joystick controller. The ACU-6 also can be computer controlled by the Masscomp via the IEEE 488 buss during the real-time data collection process. Inputs to the controller for the data collection process include elevation and azimuth scan sectors, starting position, number of repetitions of each elevation scan, and the scan rate.

The antenna controller is used with the stabilization system to provide known antenna angles during the data collection process. The stabilization system provides for four axes of position control of the antenna. They are azimuth, elevation, and pitch and roll motion of the platform (helicopter). Yaw motion of the helicopter is accommodated by inputting deviations from the heading gyro to the azimuth control axis.

During data collection the antenna angles and the platform errors in pitch and roll are recorded to later determine the actual pointing angle of the antenna during a "gulp" of data. The readout from the antenna mount also provides the elevation angle used to trigger the burst data collection gulp. During the dynamic data collection scenario when the antenna is not scanned, a pseudo angle for triggering the data collection burst is provided via an external digital clock timer.

3.4.2.5 Aircraft Positioning System. The receive aircraft is positioned in space during data collection using the Microwave Landing System (MLS) (see Section 7.0). Initial positioning of the receive aircraft is done using a separate guidance computer with a separate terminal for entering initial values for x, y, z, localizer centerline, and compass correction. This separate computer guidance program is based on the transmit system program {TRANS}. The MLS receiver data is fed directly to the guidance computer which compares the actual position to the desired position and provides the appropriate error signals to the pilot's display in the same way as in the transmitter aircraft. When the data collection program is initialized on the Masscomp all updates to the positioning program for new positions (i.e., new geometry setups) are passed from the Masscomp to the guidance computer via the DIOB. This eliminates the requirement for any further action by the operator and therefore the possibility of human error in the entry of desired position information. The MLS receiver data is also fed in parallel to the Masscomp for recording the actual position data associated with the sampled radar video data.

The scales on the pilot's display for the static tests is the same as for the transmit aircraft (coarse scale +/- 500 feet, fine scale +/- 100 feet). During dynamic data collection the scales are doubled to +/- 1000 feet in coarse and +/- 200 feet in fine scale. Modifications in the receive aircraft guidance program allows for greater than 5-mile ranges in the dynamic test that is not required for the static test.

3.4.2.6 Telemetry. A 1200-Baud data link provides the aircraft to aircraft digital communications. This allow the Masscomp controller to exercise its experiment control function by commanding the transmitter controller to change radar transmit parameters such as pulsewidth and polarization and also request parameter data and transmit aircraft position data to be recorded. Section 4.5 contains the details of this link.

3.4.2.7 Video/Voice Recorder. During data collection, the video picture of the area on the ground that is illuminated by the receive antenna beam is recorded. This is done using a video camera mounted inside the receive antenna housing allowing the video to scan with the antenna. A small hole is cut in the dish antenna with a Mylar cover to allow the camera to view the scene interrogated by the receive antenna beam. This camera has an electronic zoom lens that is set such that the field of view of the camera is roughly the same as the antenna 3 dB beamwidth. This video picture is displayed in real time to a video monitor within the aircraft so that the operator can view the area being scanned by the antenna. Another video camera is mounted behind and to the left of the operator's seat so that it views the real-time scope display of the received radar video data. This camera can alternately be repositioned to view the front panel of the ACU-6 showing azimuth and elevation angles. The video output of this camera is presented to the on-board video monitor using a screen splitter. This allows for a correlation of the antenna scanned terrain video picture to either angle information or radar video returns. The composite video from the two video cameras in a split screen format is also recorded for later viewing. Audio inputs to the recorder include all voice transmissions air-to-air, air-to-ground, and intercom conversation between crew members within the aircraft.

3.4.2.8 Diagnostics and Readiness Tests. Off line control of the system allows for various readiness tests and calibrations to be performed. Manual commands via the Masscomp controller allow for varying of the receiver parameters such as gain, bandwidth, sample time, etc. The on-board oscilloscope allows for viewing of a calibration signal as all channels are checked out. Special test programs provide for check out and calibration of various parts of the system.

During the real-time data collection, on screen status data allows the operator to monitor the system operation. This includes position information from the MLS, radar parameters, and antenna angles.

3.5 GEOMETRY ERRORS

Due to some system limitations there will be some error bound in the geometry definition. This error bound will be a direct result of the MLS position measurement accuracy, antenna pointing angle accuracy, and ground truth accuracy. Unlike other system parameters such as gain, polarization ratio, transmitter power, etc., calibration techniques cannot be used to minimize this finite error bound in the geometry. Geometry error will factor into the angle definitions associated with the normalized scattering coefficients, time of arrival used to extract the recorded radar data, and location and size of the ground patch.

3.5.1 MLS Position Data

The AN/TRQ-33 ground station transmits encoded signals over the volume of space used to position the aircraft as a function of angle. Both the azimuth and elevation angles encoded are specified for an accuracy of +/- 0.1 degree. The distance measurement equipment (DME) is reported to be accurate to +/- 1 meter. For the purpose of recording the exact location in space of the aircraft, this accuracy specification translates to a region of uncertainty in which the aircraft may actually reside while being at a reported nominal position.

For both static and dynamic data collection scenarios, the nominal positioning of the aircraft are shown in Table 3. Also included in this table are the error bounds in determining the aircraft positions in x, y, and z due to MLS reported accuracies as defined above. Further, Table 3 includes the resultant errors in the specular angle and time of arrival due to the MLS position determination accuracy. Time of arrival and specular angle errors are primarily due to errors in y and z with errors in x having only a negligible affect.

The worst cases for these errors in TOA and angle are at combinations of y min/z max (producing a positive error in both TOA and angle) and y max/z min (producing negative errors). Errors in the x dimension, while not significantly affecting TOA or angle, will translate to an error in the map registration of the specular point.

TABLE 3. GEOMETRY ERRORS DUE TO MLS POSITIONING ACCURACY

SPECULAR GEOMETRY	NOMINAL POSITIONING (FEET) X	Y	Z	POSITION ERRORS (FEET) X	Y	Z	TOA ERROR (nsec)	SPECULAR ANGLE ERROR (deg)
6	8000	9500	1000	+/-6	+/-41	+/-23	+/-6	+/-0.16
10	8000	8500	1500	+/-6	+/-36	+/-22	+/-9	+/-0.18
14	8000	6020	1500	+/-7	+/-28	+/-20	+/-11	+/-0.23
20	8000	4120	1500	+/-8	+/-22	+/-18	+/-15	+/-0.31
26	8000	3075	1500	+/-9	+/-18	+/-17	+/-18	+/-0.40
DYNAMIC	51680	0	5000	+/-9	+/-90	+/-90	+/-15	+/-0.18

From this table it is shown that errors in the geometry as determined by the MLS position data for the static geometries is approximately +/- 20 feet in the z direction, the direction most sensitive for time of arrival and angle errors. In a worst case this translates to a timing error of +/- 18 nsec. For the dynamic scenario the error bounds are much greater due to the longer range from the MLS location. In this case the error is +/- 90 feet in height (z) resulting in ±15 nanoseconds in timing errors.

The error bounds listed in Table 3 represent errors associated with those specific geometries identified. Actual errors associated with any other set-up will of course be geometry dependent. The purpose of this table is to show the relative magnitude of the error bounds for the typical scenarios presently used. Since all of the data collected will be averaged over an angle bin of 1-2 degrees minimum, the small errors shown here are of little significance. Time of arrival errors on the other hand are of much greater importance. The data reduction process will select from a time window of recorded radar data those samples associated with the boresight and main beam returns based on computed time of arrival. Errors in time of arrival will define the time resolution of the measurement system and drive the pulsewidth requirements to overcome the time of arrival uncertainty.

Another area of uncertainty in the MLS data comes from the time lag in reporting updated position information. Since the MLS reports at a 4-Hz rate there could be a 0.25 second lag in the position reported. Errors in position reporting due to time lag are due to the aircraft motion during the lag time.

In static scenarios this is of little consequence since the only aircraft motion is a result of maneuvering in an attempt to hold position in the presence of external forces, i.e. wind loads. These maneuvers are typically on the order of 5-10 feet per second which would result in reporting errors due to lag of less than 3 feet.

Position reporting lag errors are most dominant in the dynamic scenario. In this case one aircraft is moving away from the MLS at speeds of up to 300 feet per second resulting in lag errors of up to 75 feet in the "x" direction. Even though this may seem a large error, in the expanded dynamic geometry it still represents less than a 5-nanosecond error contributor in a scenario where the pulsewidth is 200 nanoseconds wide. Looking at the uncertainty in footprint location, the 75-foot error in beam position is less than 1% of the total beam footprint which covers more than 8000 feet on the ground.

3.5.2 Antenna Pointing Angles

The geometry and time of arrival are also determined by the antenna pointing angles relative to the nominal geometry defined by the aircraft positions. The transmit illumination beam is very wide (approximately 30 degrees in both azimuth and elevation) so that small errors are not considered here. The receive beam is a very narrow (approximately 2 degree) pencil beam. To determine the patch location and the time of arrival of the main beam of the receiver, both the azimuth and elevation pointing angles must be known to the best possible accuracy.

Antenna pointing angles are measured and recorded in real time in both azimuth and elevation with respect to the antenna platform. The aircraft orientation due to pitch, roll, and yaw will contribute to offsets in the actual pointing angles because of the mechanical connection between the antenna platform and the aircraft. Measurements from various sensors of these other angle inputs are provided that are recorded and used in the data reduction to compute actual antenna pointing angles to within the accuracy of the measurement devices. Pitch errors show up for the most part as polarization errors while roll is most closely coupled with the elevation pointing angle. Pitch and roll are sensed by a vertical gyro mounted on the antenna platform which measures verticality to a resolution of 0.2 degrees with an absolute accuracy of +/- 0.5 degrees. The yaw motion of the aircraft is directly related to the azimuth angle of the antenna. Resolvers on the antenna platform record the azimuth of the antenna with respect to the aircraft centerline to 6' of arc (0.1 degree). The antenna pointing angle with respect to true north is used to determine the footprint registration on the digitized map data and is determined using the signal off of the aircraft's directional gyro which is calibrated to +/- 1.0 degree. Therefore the actual azimuth pointing angle with respect to true north is only accurate to 1 degree. This is the largest error contributor in the measurement system.

3.5.3 Ground Truth

In order to determine the time of arrival of the reflected radar signal, the terrain height variations must be known. The preferred method is to digitize the area of interest using a sonic digitizer and U.S. Geological Survey Topographical maps. These maps come in various scales and degrees of resolution. They are generally available in 1:24000 scale with contour a resolution of typically 10 meters. By entering discrete points while tracing the contours in the area of interest on these maps with the sonic digitizer, the topographic terrain height information is transformed into a set of x, y, and z positions. The x and y represent the digitizer pen location on the map, and the z is the contour value being traced out. These data are then entered into an "IMSL" library routine (produced by IMSL Inc.) which accepts irregularly spaced points (i.e., x, y, and z) and a grid specification, performs a surface fit to the data, and returns terrain heights for the points on the grid. These grid point terrain heights are used in determining the time of arrival of the reflected signals within the 3-dB beamwidth of the receive antenna. This is done by tracing 9 rays from the receive antenna to the ground and back to the transmitter including the boresight ray and 8 other rays at elevation and azimuth angles ± 1/2 beamwidth from the boresight ray. (See Section 8.2.1 and Figure 74 for a more complete description.) Rays which intersect the surface-fit between grid points are assigned a terrain height based on a two-dimensional linear interpolation between the surrounding grid points. In addition, the 9 terrain heights associated with the 9 ray intersections within the 3-dB beamwidth of the receive antenna are used to determine the terrain slope and hence the normal to the surface area illuminated by the receive footprint.

For maps having 10 meter contours it may be assumed that the overall accuracy is ± 5 meters. In the worst case, i.e., for the 26 degree specular geometry, a 5-meter error in ground height can translate to an additional +/- 15 nanosecond timing error.

3.6 EQUIPMENT INSTALLATION

3.6.1 Helicopter Installation

The installation of the Terrain Measurements equipment into Army UH-1H helicopters was completed by the support subcontractor (Doss Aviation) to the Army Electronic Research Activity (AERA) at Lakehurst, NJ. The design and inspection of the installation was the responsibility of the Army through Ft. Monmouth, NJ and also approved through AVSCOM (Avionics System Command) in St. Louis, MO. Upon final completion of the installation, test pilots from Edwards AFB, CA flew each aircraft, evaluated its flight performance, and set operational limits before letting an air worthiness release. Since the initial installation and flight tests, several modifications to the equipment have occurred. The magnitude of these changes, however, have been such that additional flight tests were not required. The updated air worthiness releases have been signed by the inspectors from Ft. Monmouth, NJ. Figures 21 and 22 show the two UH-1S referred to as the transmit aircraft and receive aircraft respectively.

The installation tasks performed by the Army and support groups included the following:

Built and installed antenna positioner mounting structures for each helicopter.

Built and installed vibration isolated equipment racks in both helicopters.

Modified the receive helicopter to accept the 4' dish antenna. This included removal of the right-hand cargo door, cutting out a portion of the roof, and manufacturing and installation of a removable wall to seal the cargo area from the outside environment.

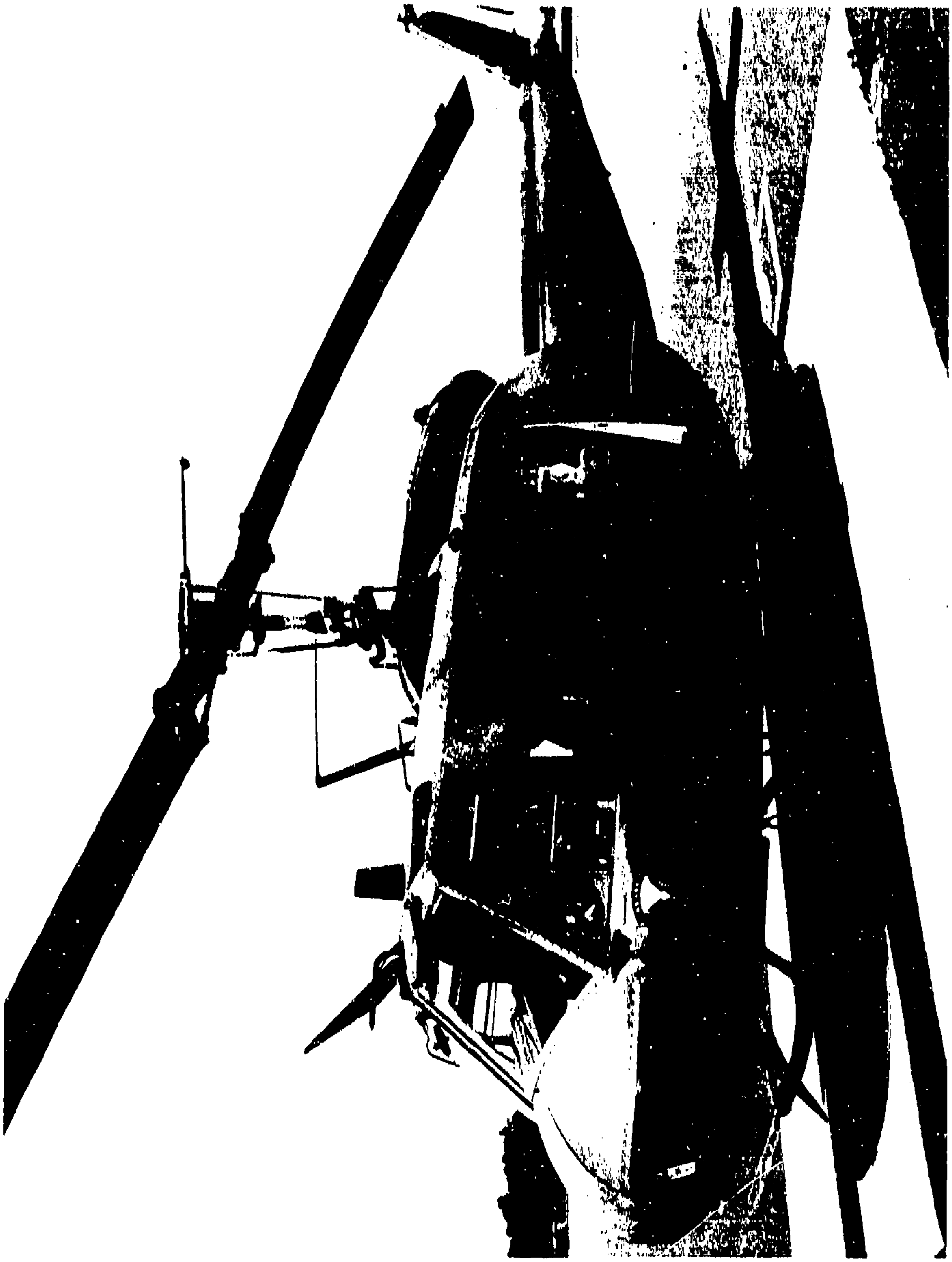


Figure 21 TRANSMIT HELICOPTER

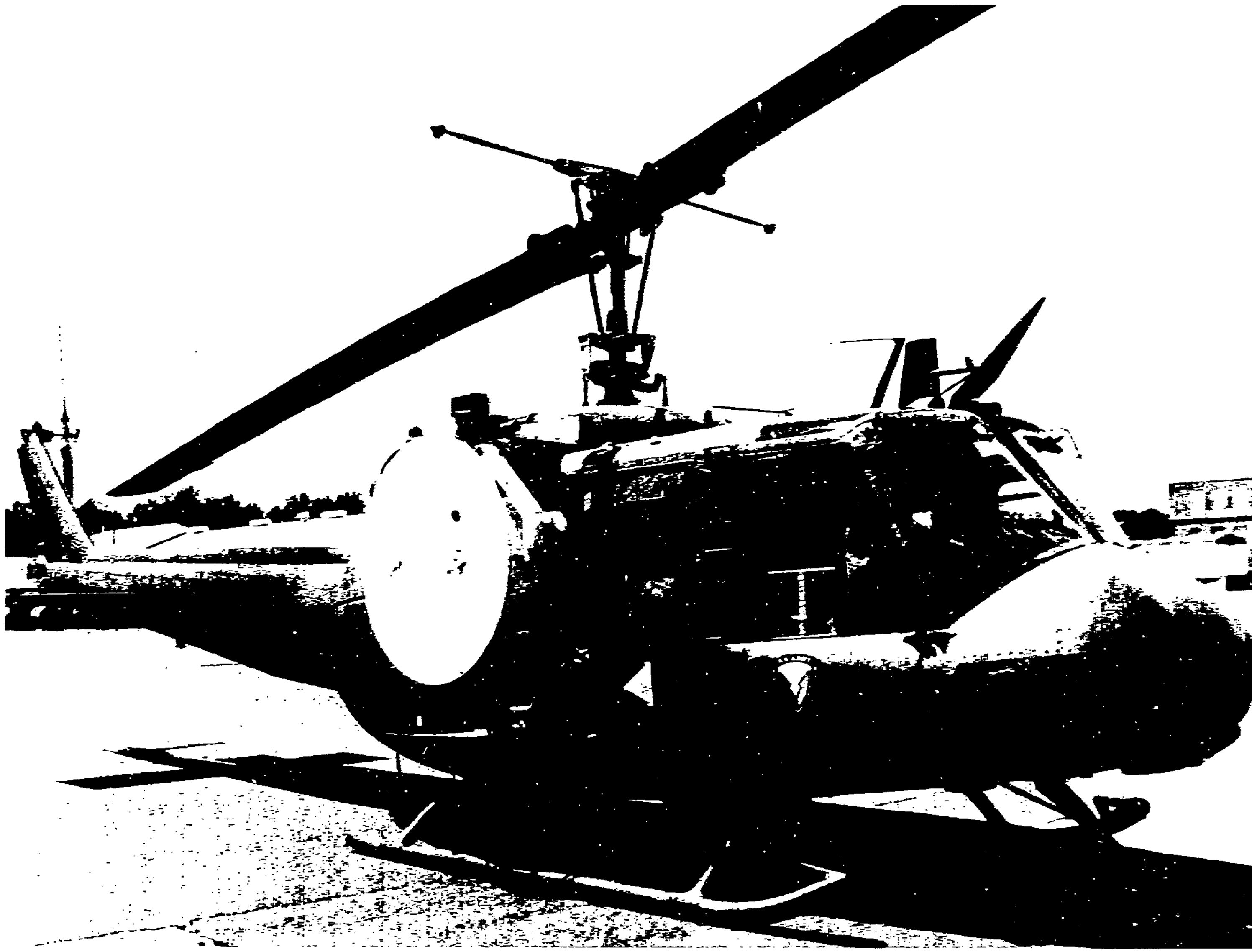


Figure 22 RECEIVE HELICOPTER

Modified the transmit helicopter for the transmit antenna. This included cutting out a portion of the left side cargo door and manufacturing and installation of a wall to seal the cargo area from the outside environment.

Installed the pilot's and co-pilot's instrumentation display for station keeping in both aircraft. Also built and installed the interface for this instrument (see Figure 23).

Installed 400-Hz rotary inverters provided by the Army in each aircraft to supply the required 400-Hz power to the equipment.

Installed 60-Hz static inverters provided by Calspan in each aircraft to supply the required 60-Hz power to the equipment.

Provided and routed suitable wiring in each aircraft
a) for ship's 28 VDC, 400 and 60 Hz AC to equipment
b) for heading gyro to antenna positioners
c) to/from the pilot's display
d) for radio and intercom to the operator location

Maintained weight and balance records for each aircraft.

Since much of the Calspan equipment included commercial units, the helicopter environment (specifically the vibration environment) had to be accommodated. The various equipment units were mounted on aluminum panels manufactured by Calspan. The dimensions, weight, approximate center of gravity, and desired location for each panel within the aircraft was provided to Doss who in turn selected special vibration isolators for each panel to be installed in the equipment racks.

Figure 23. PILOT'S DISPLAY

The design of the equipment racks must withstand a minimum 8-G force impact as required by the UH-1H safety criteria. Additional safety precautions designed into the installation included: circuit breakers on the pilots console to disable all power to the cargo area equipment, clear access for the operator to both emergency side exit doors, clearance over the equipment racks for the operator to reach a front exit if needed, and tether lines on the receive antenna to restrict its fall in case of a failure in the antenna stabilizer mount.

3.6.1.1 Transmit Helicopter Installation. The transmit equipment is contained in three equipment racks in the cargo area. The operator's seat is just forward of the transmission housing such that there is easy access to all equipment. Figure 24 shows the floor plan of the cargo area. The transmit antenna is mounted to the left of the transmission housing where it looks out the modified (cut away) cargo door. An extra wall enclosure has been added as indicated to seal off the cargo area from the outside environment. A plexiglas window in this wall allows the operator to view the antenna and positioner during ferry flights and data collection.

Two racks directly in front of the operator's seat (racks A and B) are approximately 2 feet wide, 2 feet deep, and 3 feet high. These racks hold most of the transmit system equipment. Rack C to the left of the operator's seat holds the transmit TWT amplifier and the exciter unit. This rack is not as tall, only about 2 feet high, allowing the operator easy access to the emergency exit door. Figure 25 shows the rack layout of the transmit system, identifying the major components. Figures 26 and 27 are photographs taken of the transmit system as it is installed in the helicopter.

The operator normally enters through the right-hand cargo door. There is sufficient seating in the transmit

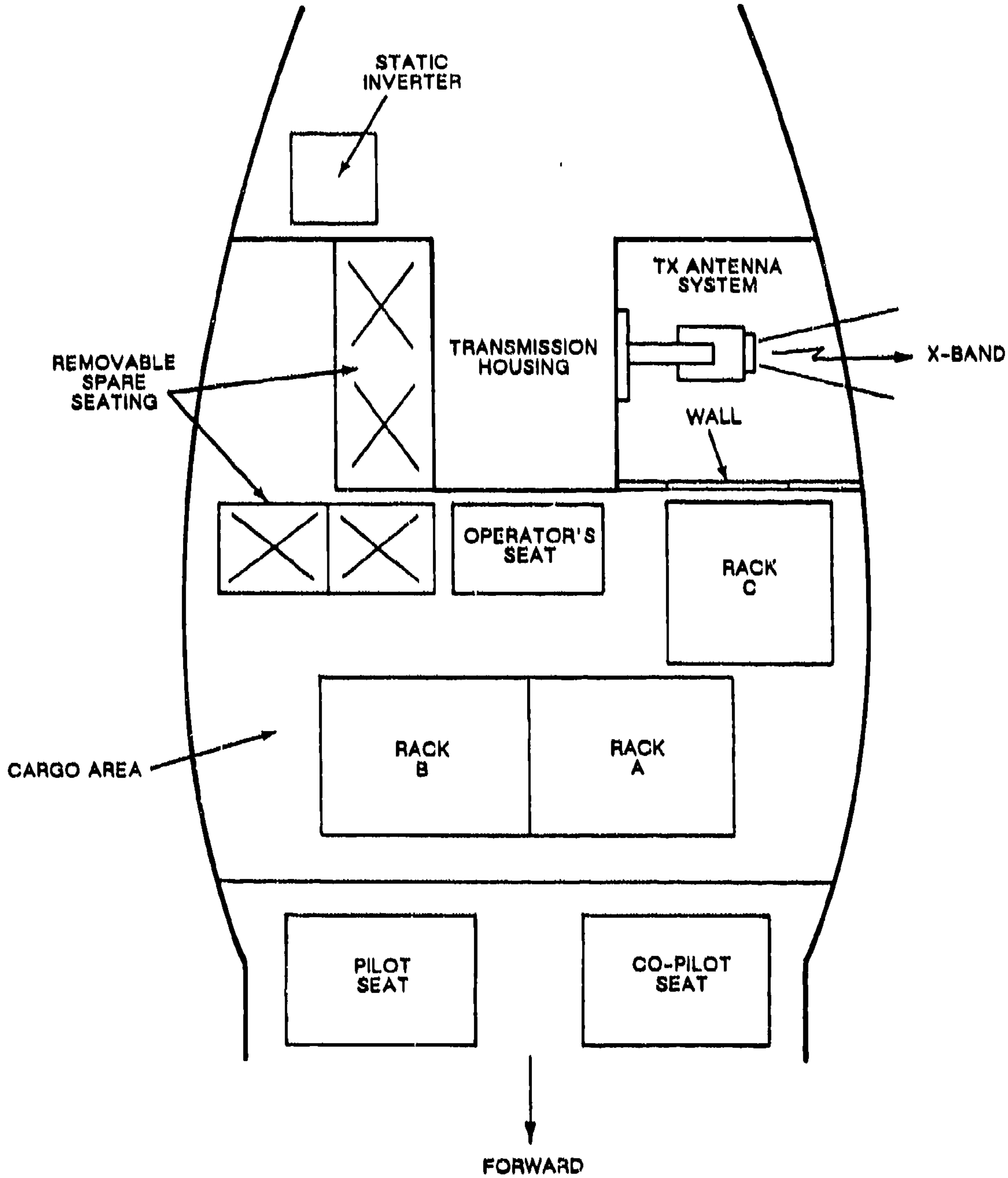


Figure 24. TRANSMIT HELICOPTER FLOOR PLAN

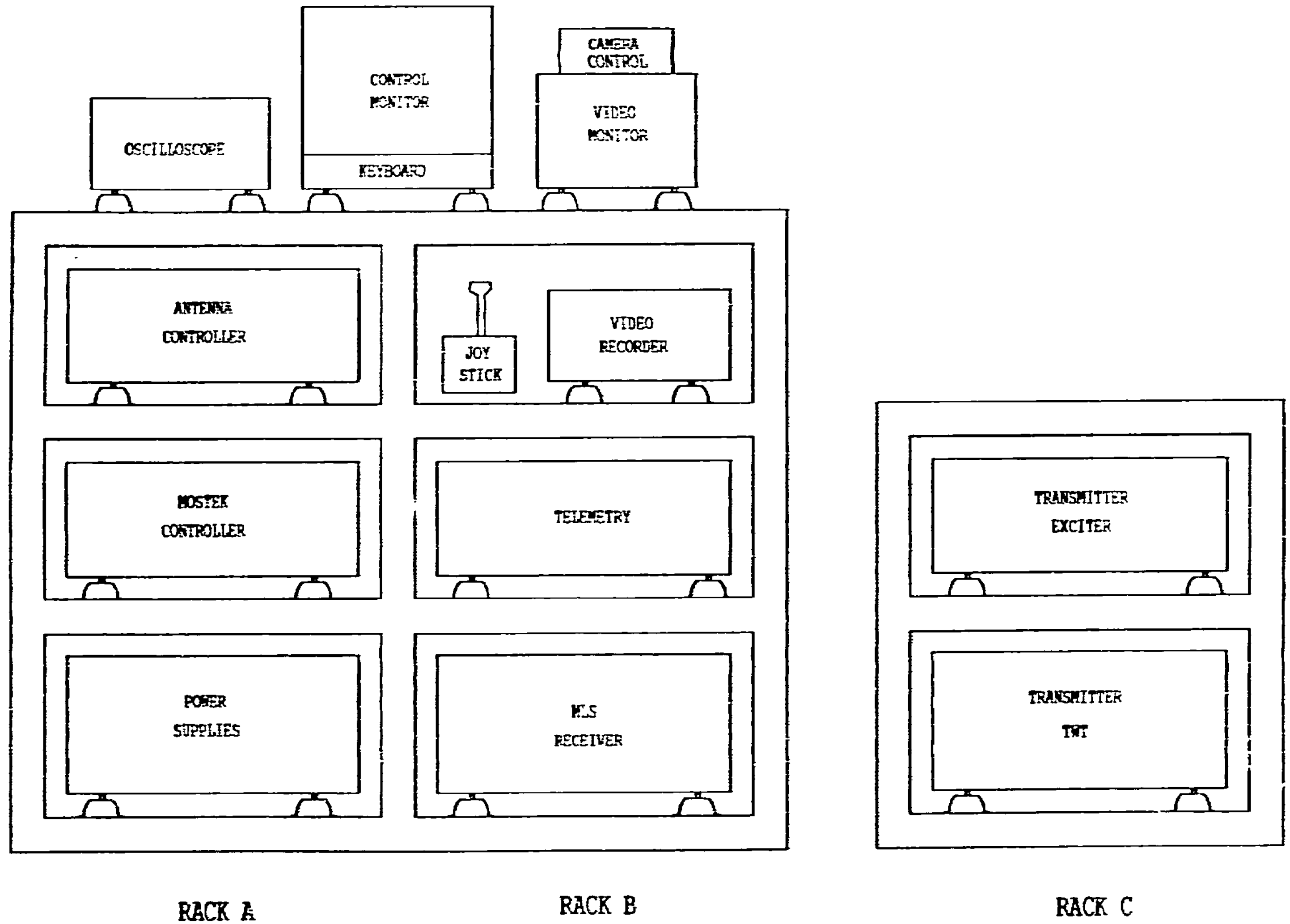


Figure 25. Transmitter Equipment Rack Layout

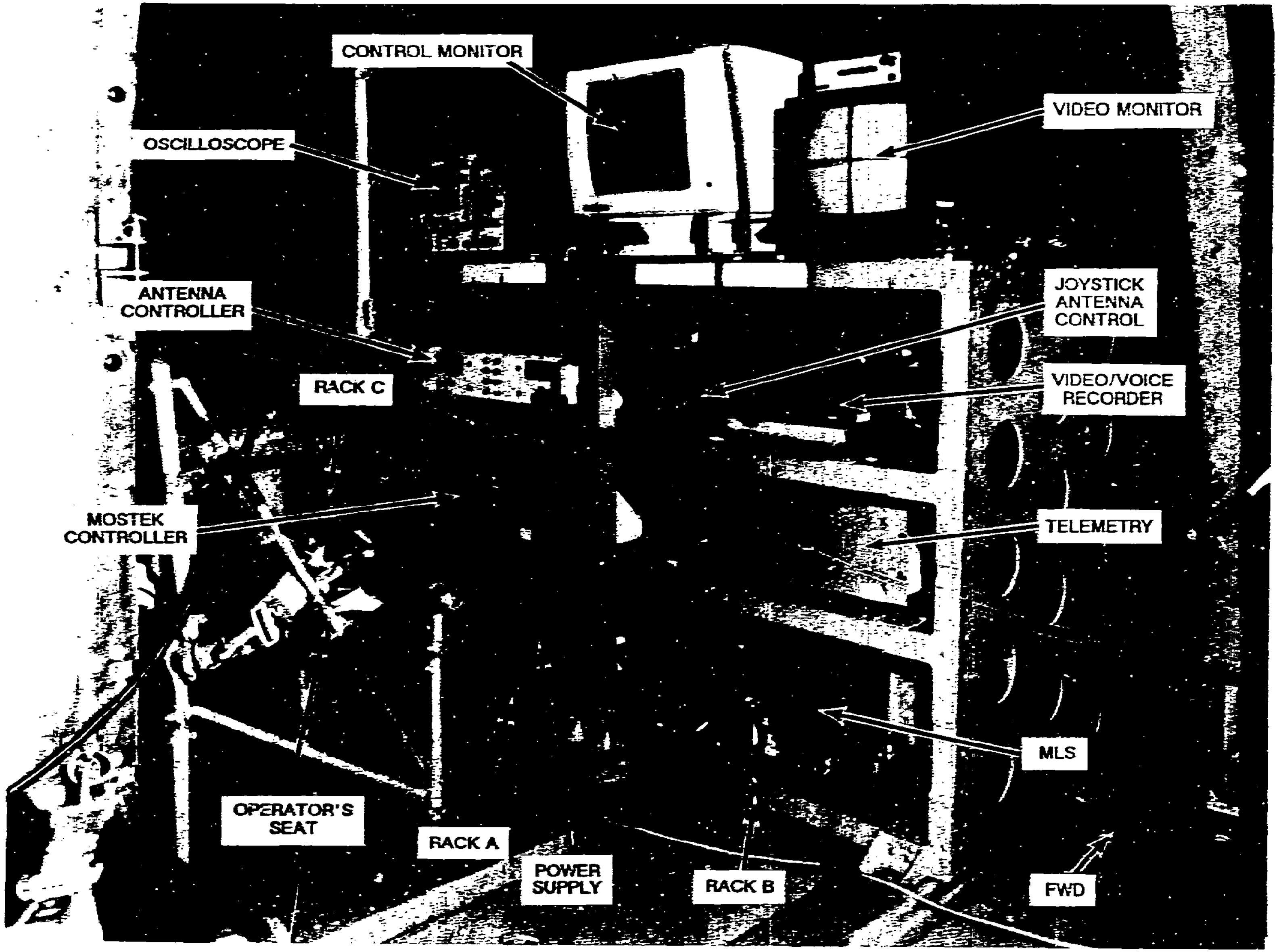


Figure 26. TRANSMIT HELICOPTER EQUIPMENT INSTALLATION

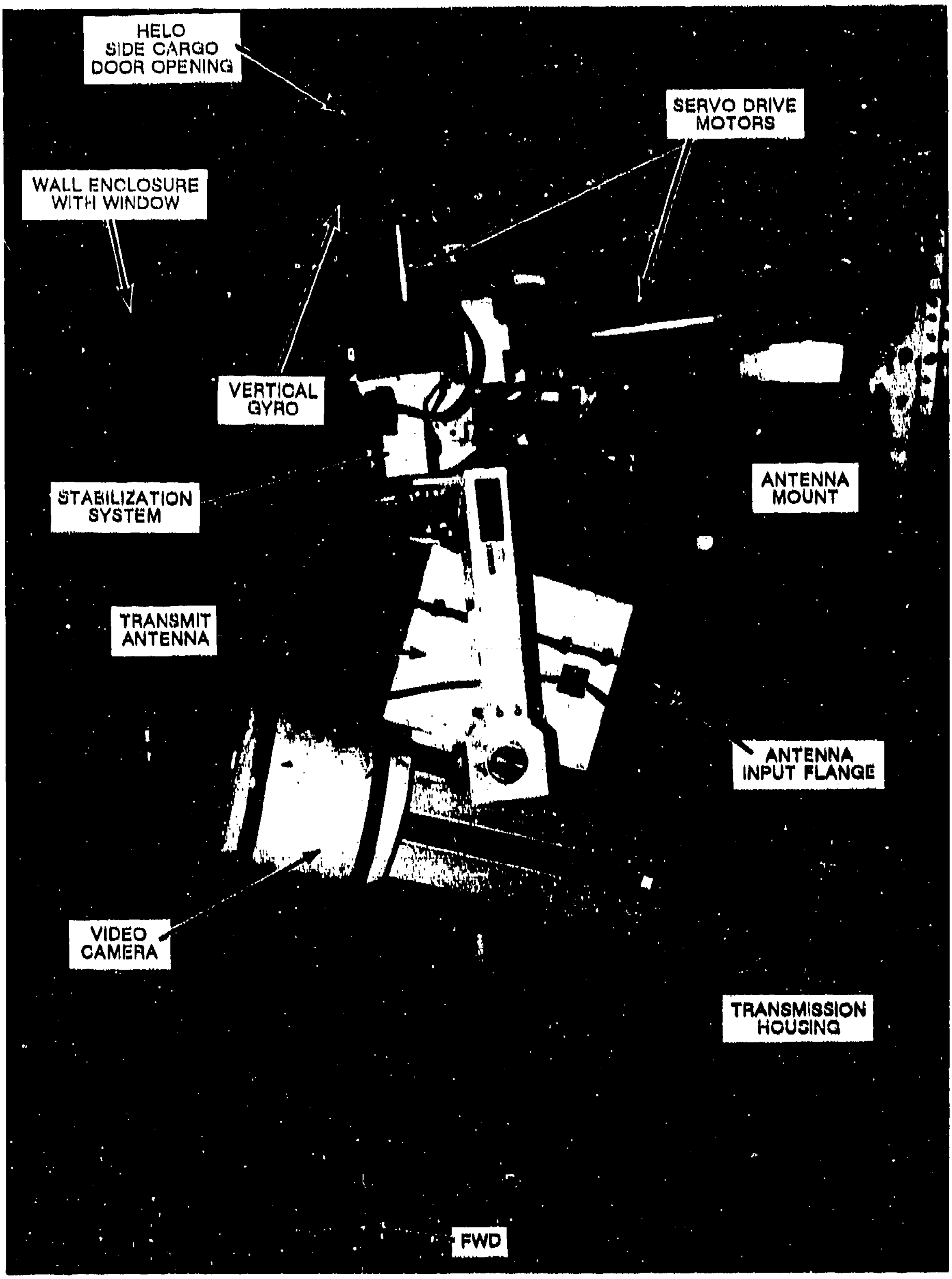


Figure 27. TRANSMIT HELICOPTER ANTENNA INSTALLATION

helicopter to carry four additional passengers, including the crew chief, besides the operator and two pilots.

3.6.1.2 Receive Helicopter Installation. The equipment for the receive helicopter installation is contained in four equipment racks supplied by the Army. The RF receiver assembly is contained in a specially built aluminum box that is installed on the floor of the cargo area behind the receive antenna. As in the transmit helicopter, the operator sits just forward of the transmission housing facing the three main racks. The Masscomp computer is housed in the fourth rack around the corner of the transmission housing but is still accessible to the operator. Figure 28 shows the floor plan of the receive helicopter.

The receive antenna is mounted on the right side of the helicopter where it is suspended outside the aircraft. An extra wall enclosure has been added as indicated to seal off the cargo area from the outside environment. A plexiglas window in this wall allows the operator to view the antenna during flight. As shown if Figure 29 , a portion of the roof has been cut away to allow the antenna to scan without hitting the aircraft. During ferry flights the antenna is pinned with aluminum struts in a fixed position. This allows for a greater forward airspeed since the stabilizer motors do not have to hold the antenna in position. During data collection these struts are removed to allow the antenna to scan freely. During this time a forward airspeed restriction of 30 knots is imposed so as not to overtax the stabilization motors.

The racks directly in front of the operator (racks A, B, and C) are each approximately 2 feet wide by 2 feet deep. Racks A and B are approximately 3 feet high. Rack C is only about 1.5 feet high allowing the operator access to the emergency exit door on the right. The fourth rack, rack D, holds the computer and is approximately 2 feet wide by 2 feet high and is 3 feet deep. Figure 30 shows the rack layouts for the receive system, identifying

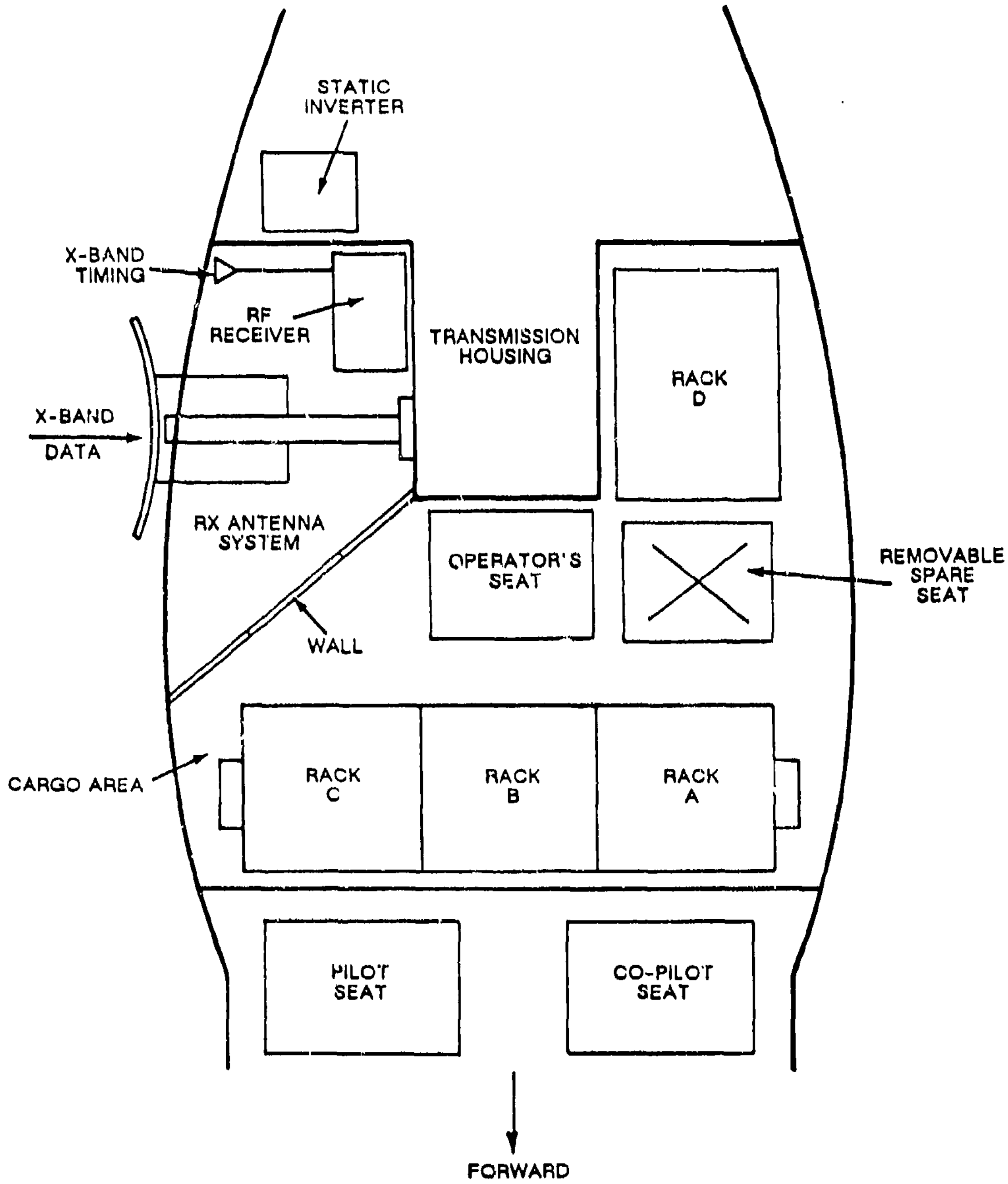


Figure 28. RECEIVE HELICOPTER FLOOR PLAN

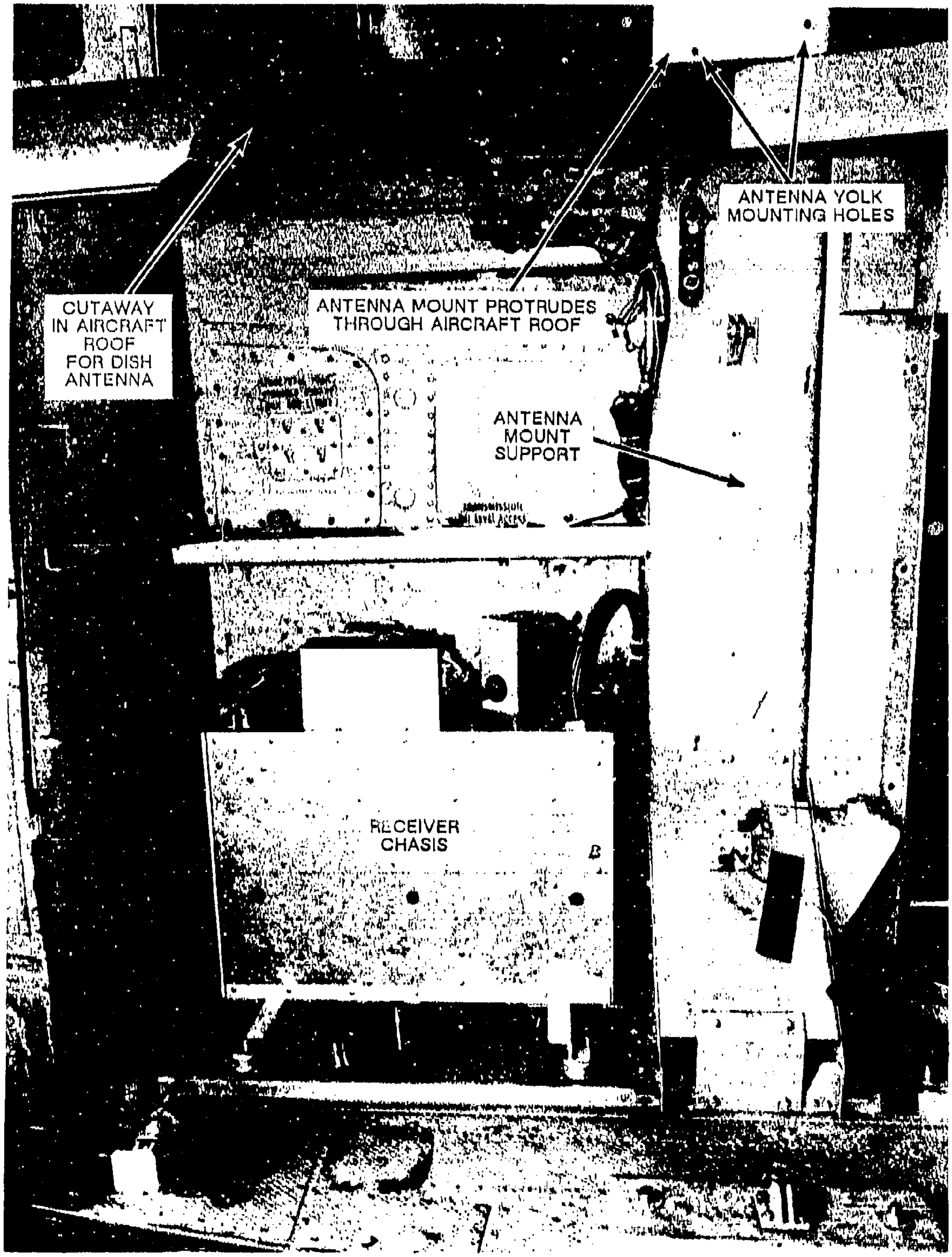


Figure 29 RECEIVE HELICOPTER ROOF MODIFICATION

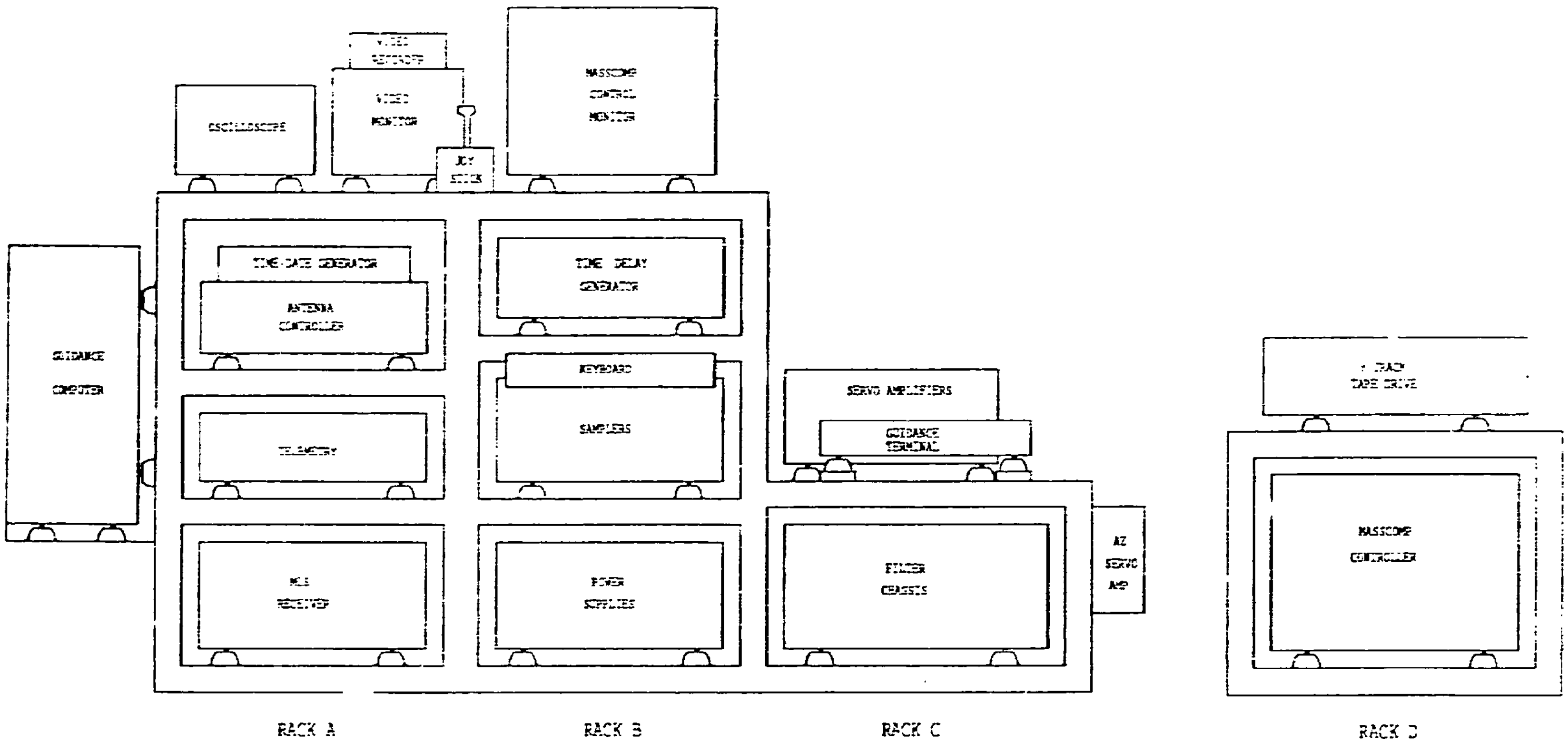


Figure 35. Receiver Equipment Rack Layout

the major components. Figures 31 through 35 are photographs taken of the receive system as it is installed in the helicopter.

The operator normally enters the aircraft through the left-hand cargo door. There is room for one extra passenger in the cargo area besides the operator. This seat is used by the crew chief during ferry flights and may be used by an observer during static data collection. In some conditions, this seat is unoccupied to conserve weight. During the dynamic data collection tests this seat is often used by a second operator to coordinate the communications with the Aztec allowing the equipment operator to concentrate on the data collection operation.

3.6.2 Aztec Installation

For dynamic data collection, the transmitter equipment is moved from the helicopter to a Calspan owned fixed wing aircraft, the Piper twin engine Aztec. Installation preparations and special mounting brackets and cable assemblies for the transmit equipment were completed by Calspan's Flight Research Department. Moving the equipment from the transmit helicopter to the Aztec (or vice versa) is done in the field and requires approximately 30 manhours.

The transmit equipment is installed in the passenger area behind the pilot seats and in the cargo compartment in the rear. The second passenger seat is removed. Figure 36 shows the floor plan of the Aztec installation. The transmitter exciter and TWT rack (Rack C) from the helicopter installation forms the base of the Aztec installation. Other needed equipment panels are removed from the racks in the transmit helicopter and mounted on this rack. This includes the Mostek controller, the control monitor and keyboard, and the telemetry unit. Figure 37 shows this rack reconfiguration for the Aztec installation. The power supply panel and MLS receiver panel are mounted in the cargo area behind the passenger area.

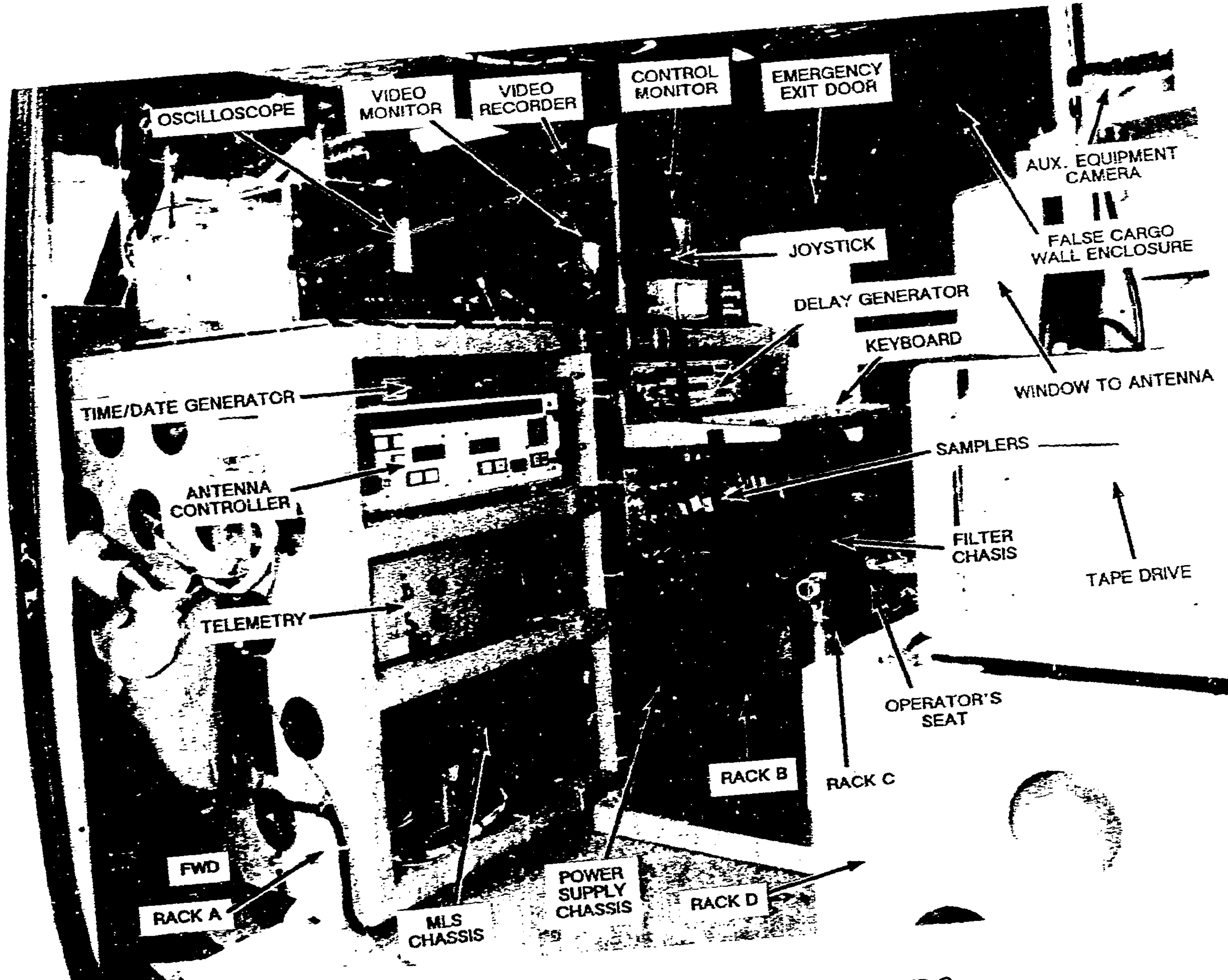


Figure 31. RECEIVER INSTALLATION RACKS A, B, AND C

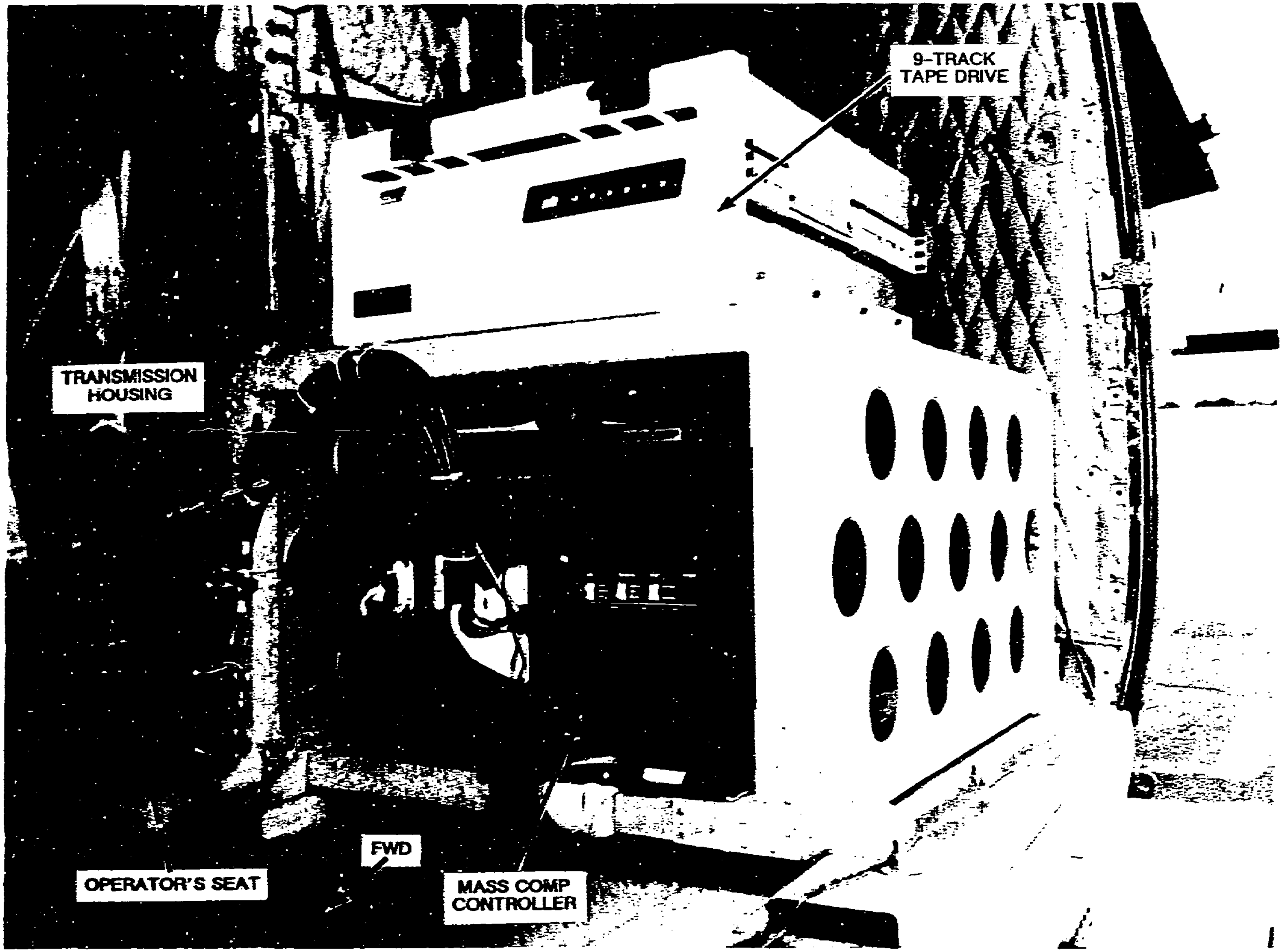


Figure 32. RECEIVER INSTALLATION RACK D

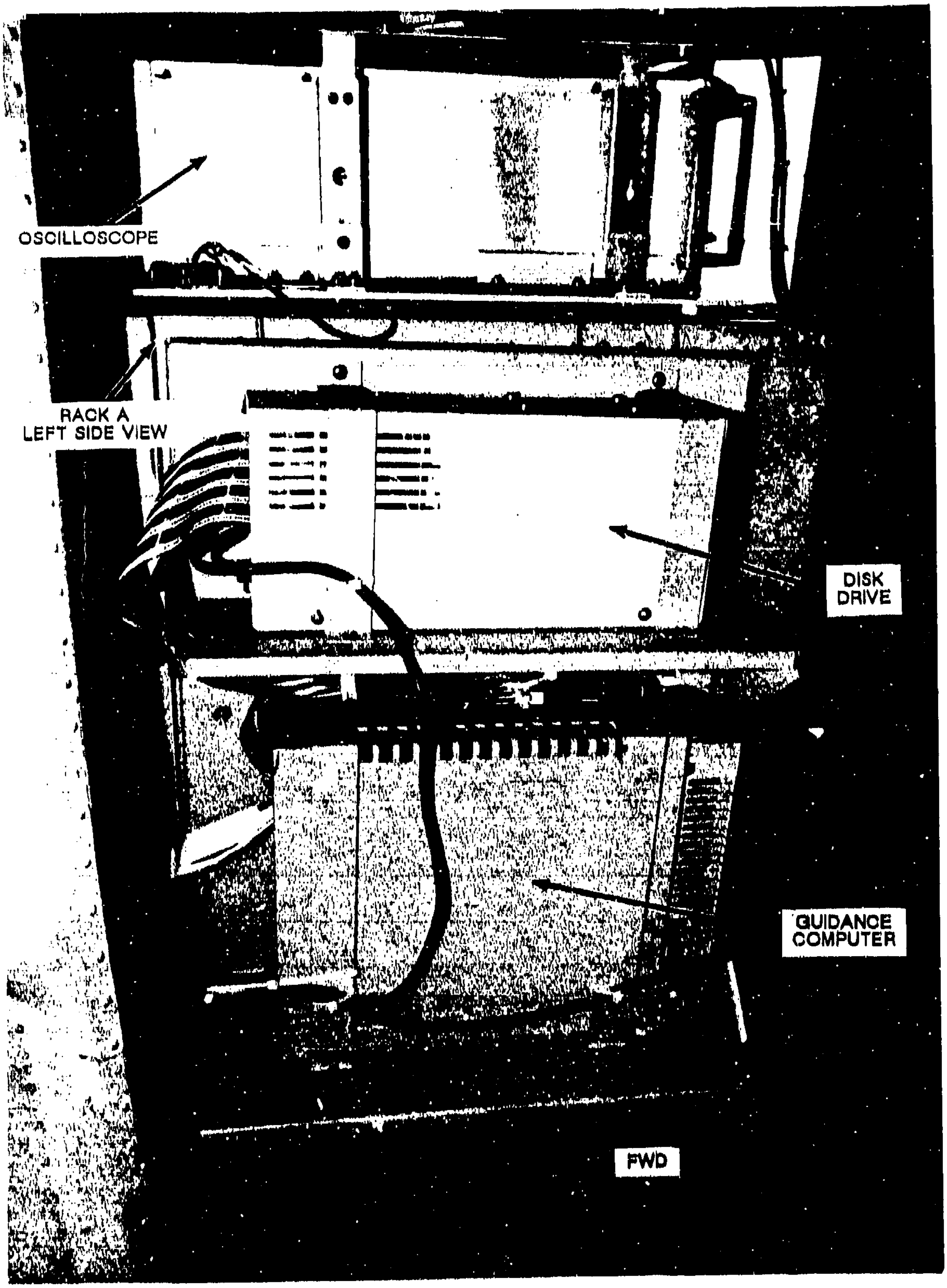


Figure 33. RECEIVE AIRCRAFT AUXILLARY GUIDANCE COMPUTER (NEW MODIFICATION)

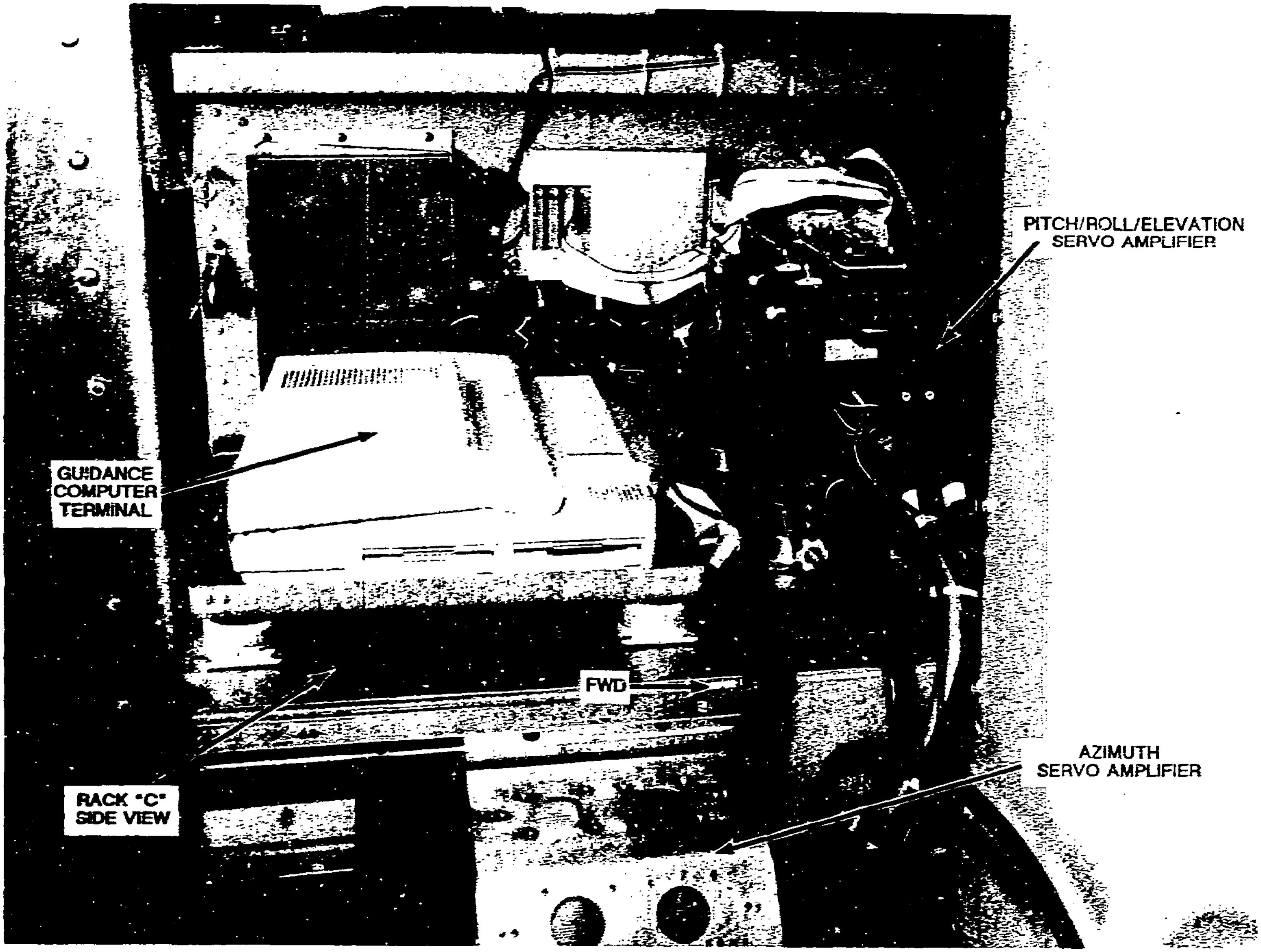


Figure 34 SEPARATE GUIDANCE TERMINAL MODIFICATION

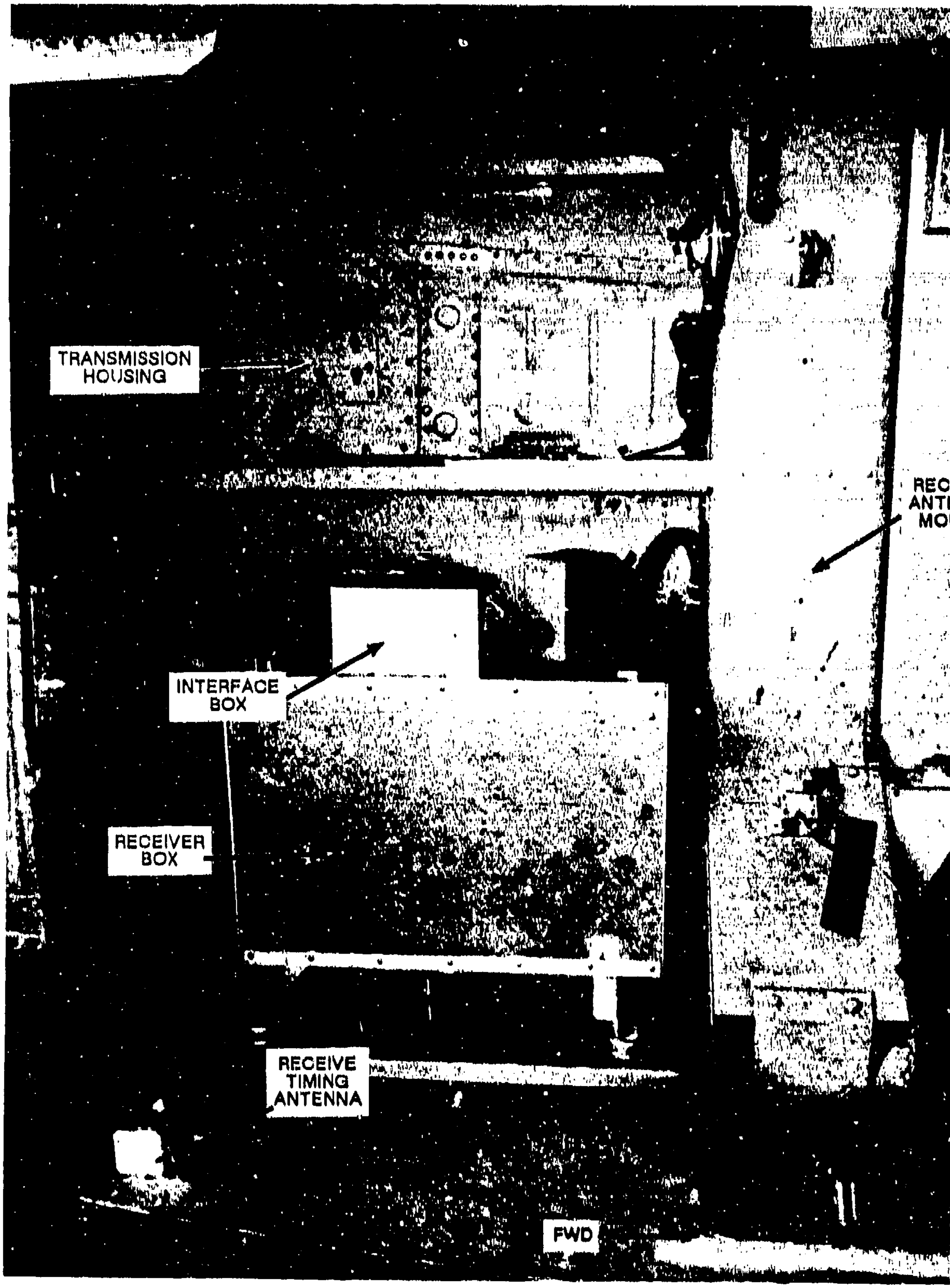


Figure 35. RECEIVER INSTALLATION

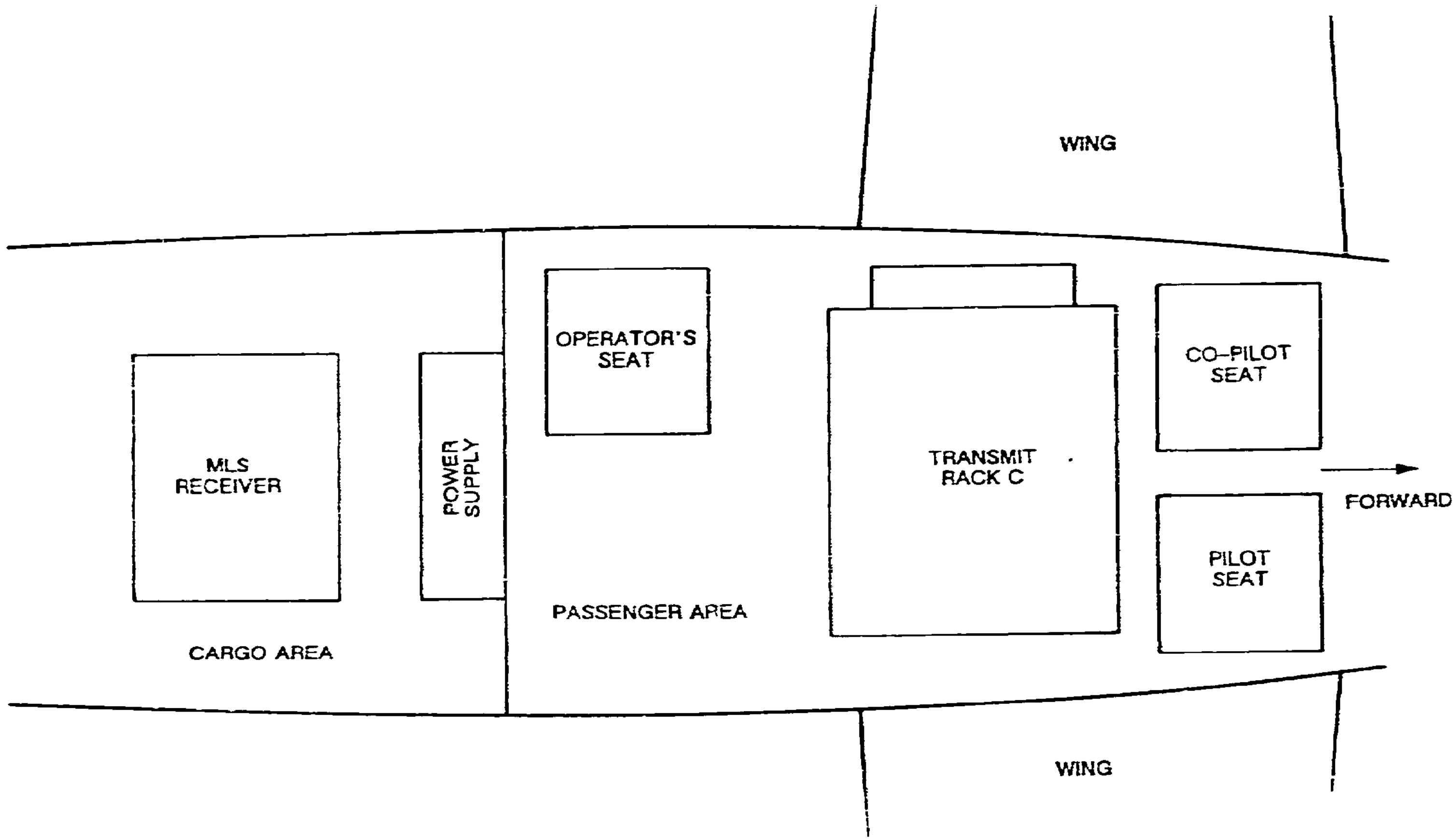


Figure 36. AZTEC INSTALLATION FLOOR PLAN

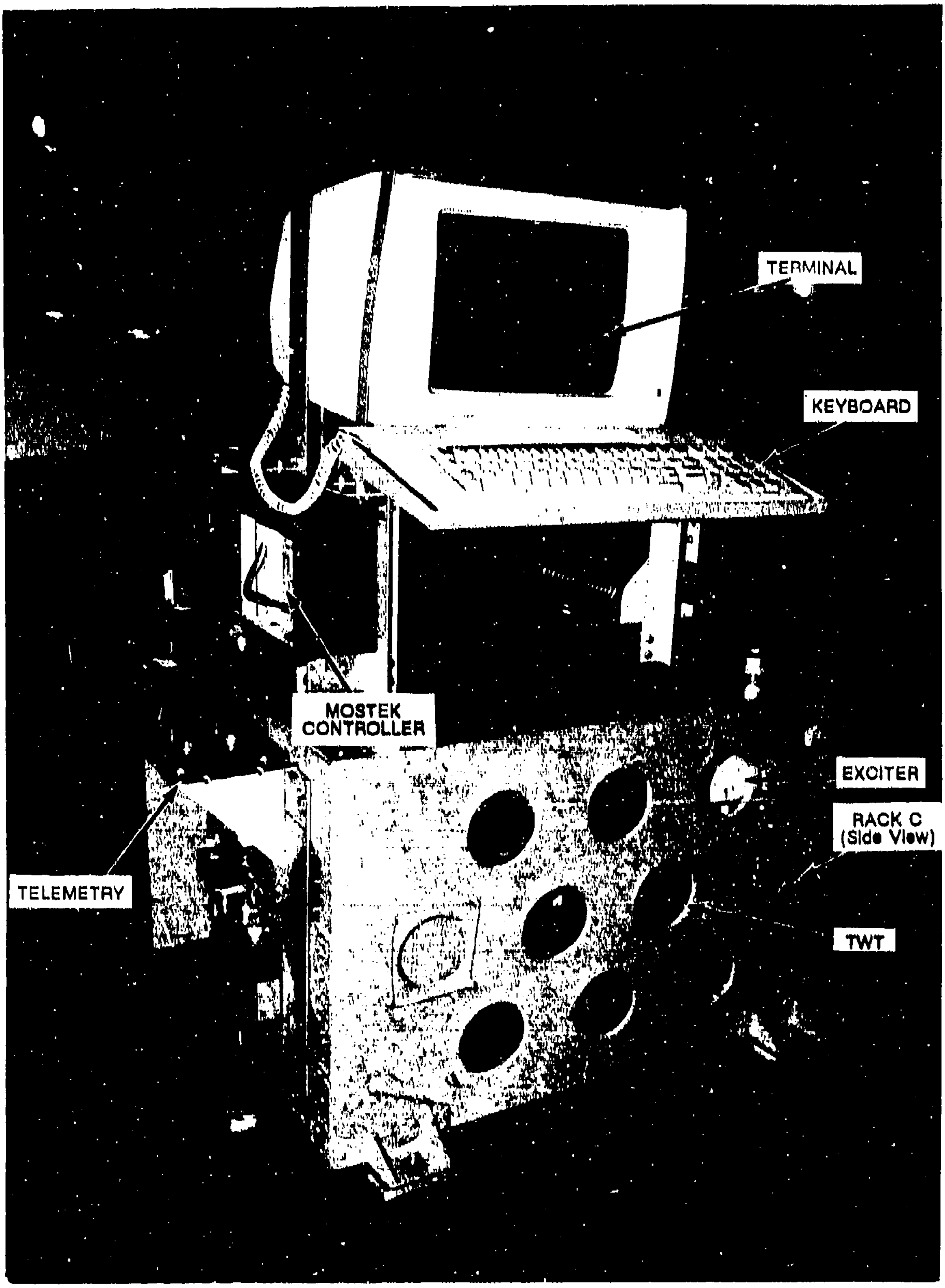


Figure 37. TRANSMITTER RACK C MODIFIED FOR AZTEC INSTALLATION

Figures 38 through 41 are photographs of the equipment as it is installed in the Aztec.

The transmit antenna is installed in a fixed pointing position on the belly of the aircraft so that it illuminates the ground below and forward of the Aztec. The stabilization system is not used for the Aztec installation so that any pitch, roll, and yaw motion of the aircraft will directly effect the pointing angle of the antenna.

The timing antenna is mounted on the roof of the aircraft for a clear line-of-sight to the hovering helicopter above. The telemetry antenna is mounted on the nose so that it also has line-of-sight to the receive helicopter. The MLS antenna is also mounted on the belly of the Aztec. Its orientation is to the rear so that, as the Aztec overflies the MLS on a heading towards the hovering helicopter, it picks up the MLS transmissions. See Section 2.2 for the description of the dynamic data collection scenario.

Besides the stabilization system, the video system and oscilloscope are also not included as part of the Aztec installation. There is no means of monitoring the transmitted pulse other than the power monitor readout nor is there a video picture of the terrain recorded as the aircraft overflies the testing area. An on-board tape recorder provides voice recordings during flight.

3.7 SPARE PARTS

Spare parts for the system were purchased to ensure the least chance of a long-term down time due to equipment failures. These items were selected based on 1) probability of failure, 2) projected delivery time of replacement parts, 3) projected repair times of failed parts, and 4) cost.

Components in the RF systems of both the transmitter and receiver are typically long lead items. For this reason sufficient

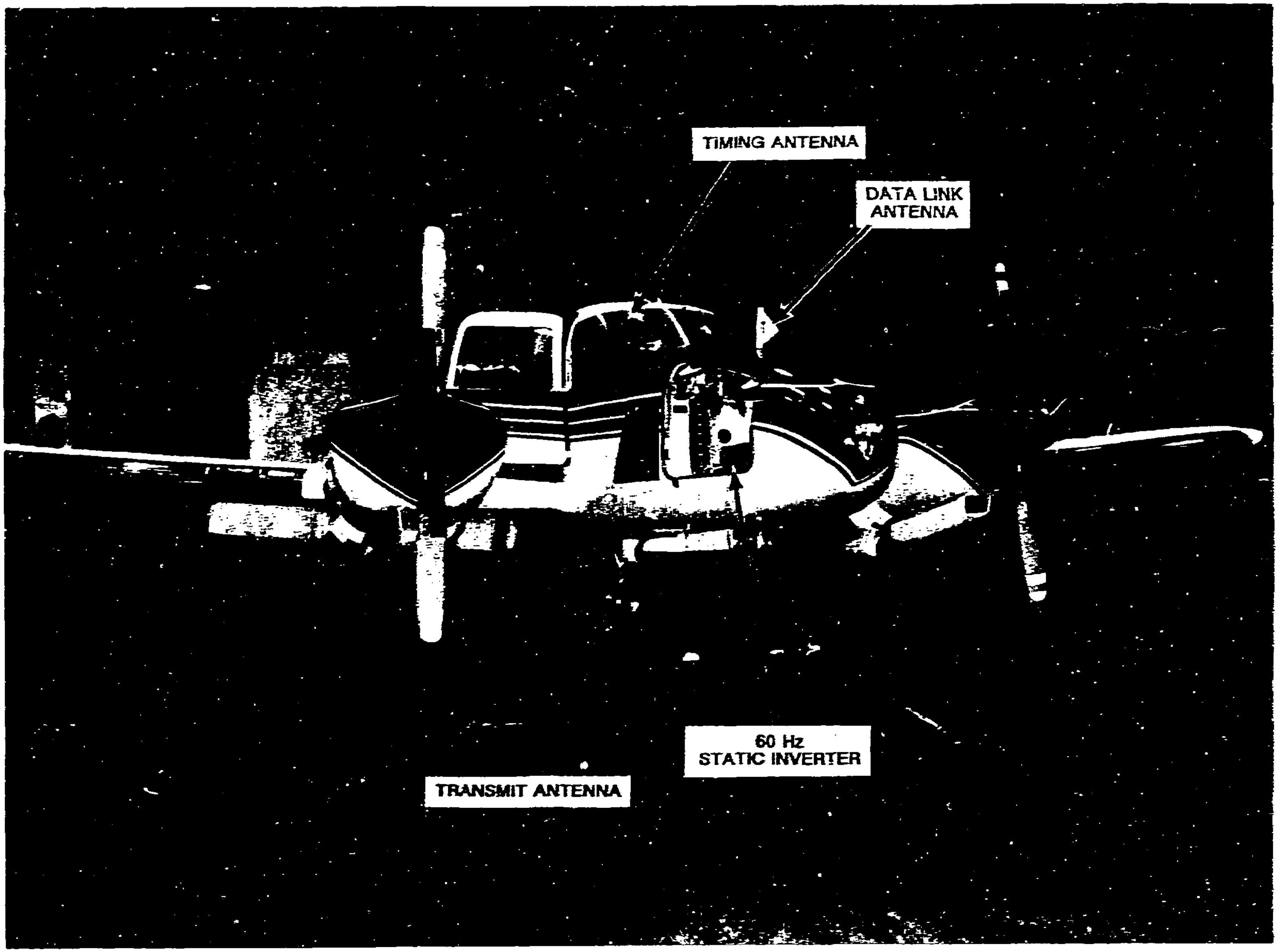


Figure 38. AZTEC AIRCRAFT USED FOR DYNAMIC TESTS TRANSMITTER PLATFORM

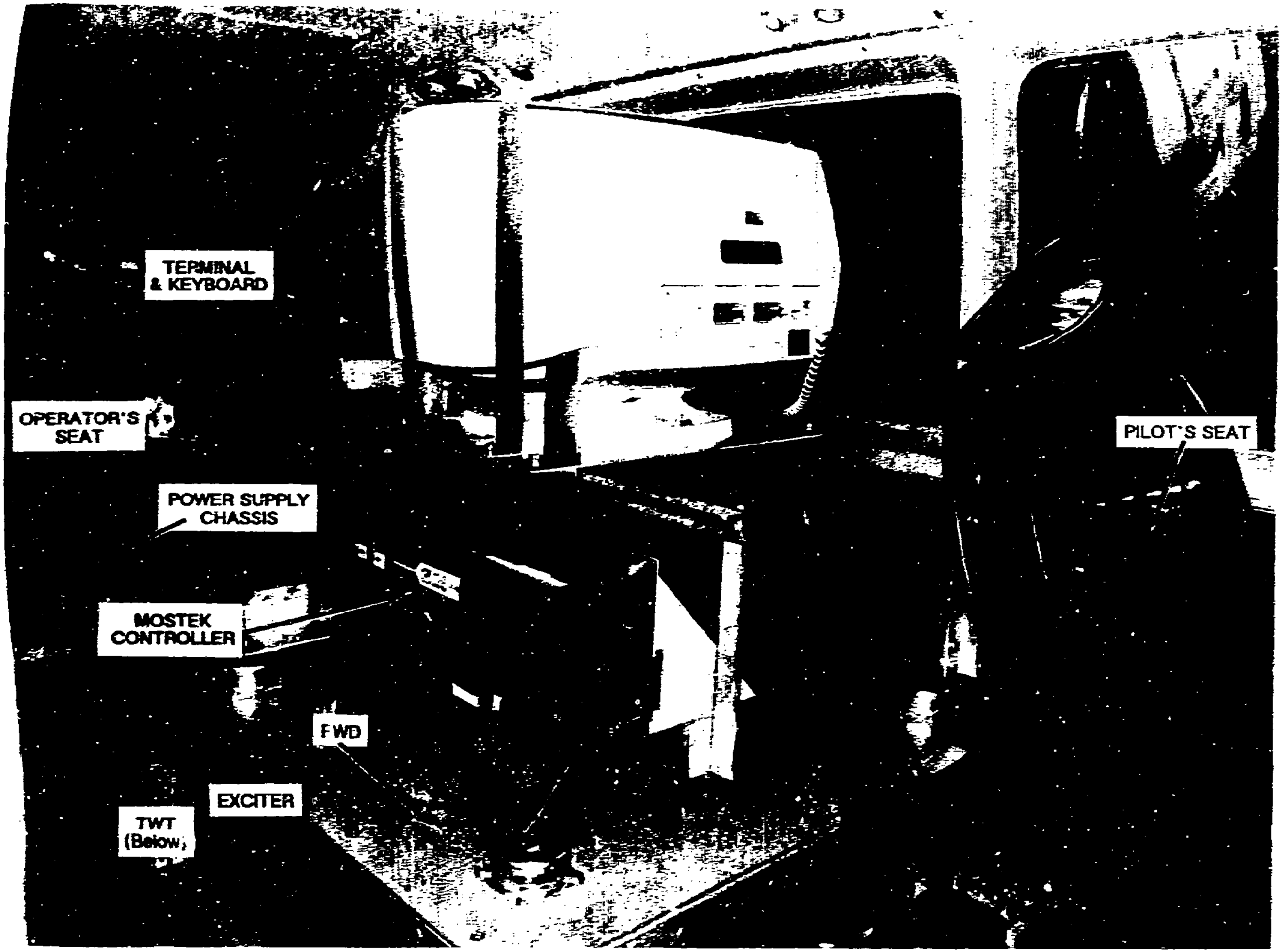


Figure 39. AZTEC INSTALLATION CABIN AREA

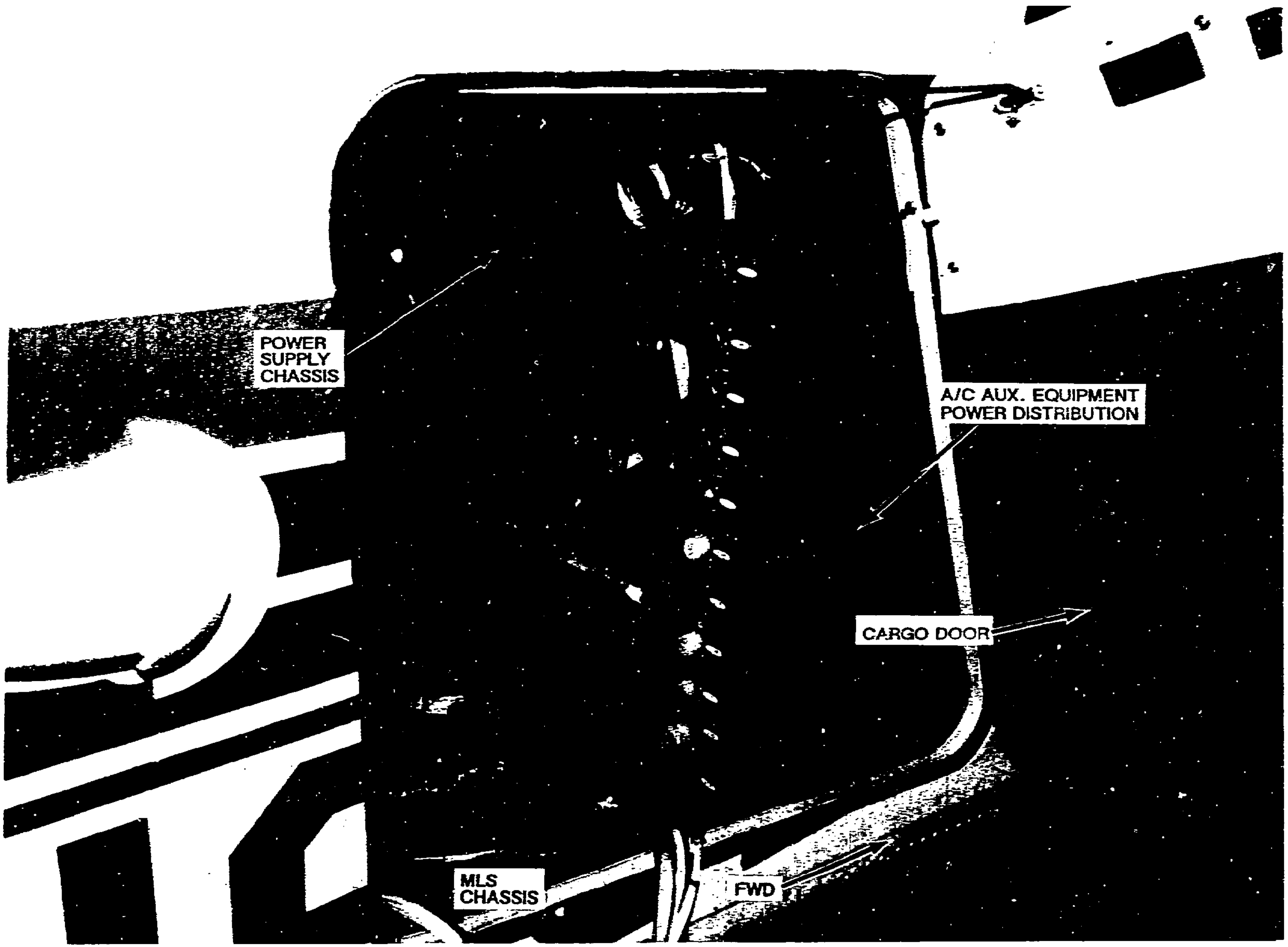


Figure 40. AZTEC REAR CARGO AREA

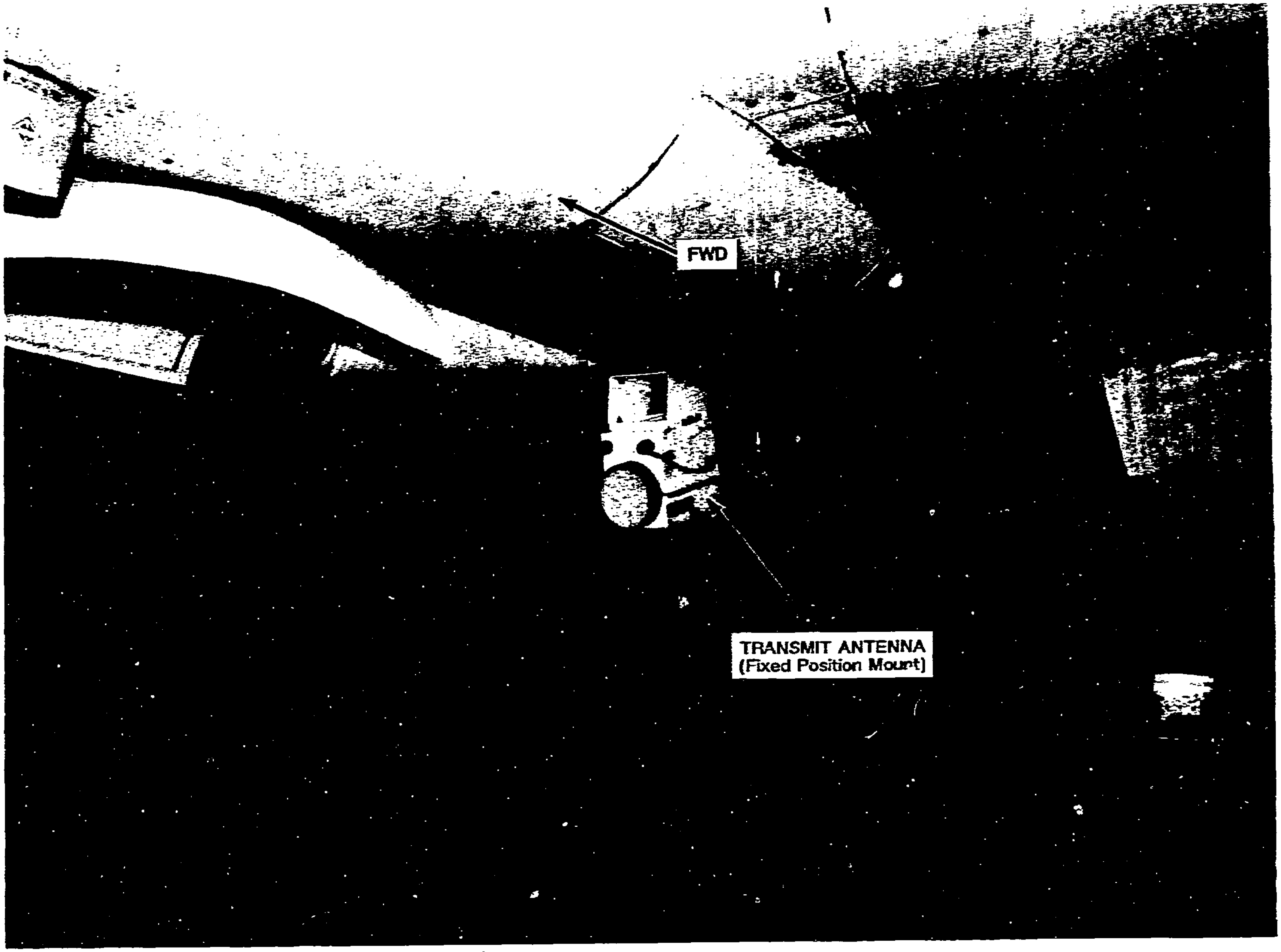


Figure 41. AZTEC INSTALLATION OF THE TRANSMITTER ANTENNA ON THE BELLY

spares were purchased that would allow for in-the-field repair of almost every part of the RF systems.

Experience with the stabilization systems, particularly the receive system, indicated the necessity for a complete set of spare parts including motors, gears, pins, etc.

Various ICs and digital components, cables, and connectors were purchased since their cost was minimal compared to even one down day in the field.

Some of the large critical items in the system which could effectively shut down the field operations were not purchased based on their cost even though repair or replacement times could be very long. These included the transmit and receive antennas, stabilization systems, computer systems, and Rubidium atomic reference sources. Table 4 contains a list of spare parts that have been purchased.

Table 4
SPARE PARTS PURCHASED

Quantity	Item	Manufacturer	Quantity	Item	Manufacturer
1	Roll Gear	Oliver Gear	1	TWT	Litton
1	Pinion Gear	Oliver Gear	2	X-Brand Source	Comm-Tech
2	Roll Gears	Oliver Gear	1	Log IF Amp	RHG
2	Pinion Gear	Oliver Gear	1	Power Amp	Avantek
1	Rate Gyro	U.S. Time	1	Power Divider (8-Way)	Anaren
1	Motor Gear Head	Electro Craft	1	Power Divider (4-Way)	Anzac
1 Lot	Integrated Circuits	Various Suppliers	1	Hard Disk Drive	Atasi
2	OP Amps, OPA511AM	Burr Brown		Integrated Circuits	Various
3	OP Amps, OPA511AM	Burr Brown	2	Prog. Attenuator	Hewlett-Packard
1	IEEE Interface Board	Ziatech	1	Phase Shifter	Arra
1	Motor Gearhead, 350-003-001	Electro Craft	1	Directional Coupler	Anaren
1	Motor Gearhead, 552-004-116	Electro Craft	2	AMP RF	Avantek
3	Programmable (ECC) Delay Lines, 2TTLD6-20-1	Engineered Components	2	Video AMP	Comlinear
			3	Coax Isolator	Junction Devices
2	Linear Amplifier CLC-10°	Robtron	2	RF Filter	Cir-Q-Tel
2	OP Amps, OPA511AM	Burr Brown	1	90° Hybrid Coupler	Anaren
2	Rate Gyros	U.S. Time	1	2-Way Power Divider	Anaren
2	OP Amps, OPA511AM	Burr Brown	2	DB Mixer	Anaren
1	Syncro 11 CX4E (New w/Certs)	Clifton Precision	1	RF ECL Switch	M/A-Com
1	Syncro (New Surplus)	Harowe	1	Single Pole-4 Throw Switch	K&L Microwave
4	Precision Pot 1K	AST	1	LP Filter 250MH-2	Cir-Q-Tel
2	Pitch Gear	Oliver Gear	1	LP Filter 85MH-2	Cir-Q-Tel
2	Pinion Gear	Oliver Gear	1	LP Filter 20MH-2	Cir-Q-Tel
15	74ALS 92N IC	Various Suppliers	1	SR255 Fast Sampler	Stanford
10	74ALS 20AN IC	Various Suppliers	1	Servo Anti-Backlash Gearbox	Winfred M. Berg
10	74ALS 30AN	Various Suppliers	1	Timing Belt Pulley - 80 Teeth	Winfred M. Berg
15	74ALS 240AN	Various Suppliers	1	Timing Belt Pulley - 20 Teeth	Nordex
15	74ALS 373N	Various Suppliers	2	Timing Belt (Steel)	Nordex
12	BNC to BNC Barrel Conn.	Amphenol	1	Precision Bellows Coupling	Nordex
15	Res. Network 16 Pin Dip 560 Ohm	Bourn	3	Motor Gearhead 180:1	B&B Motor & Con.
1	Double-Shafted Gear Head	B&B Motor Con.	3	OP Amp OPA511AM	Burr-Brown
6	IC - A/O Conv. MP 758/JN	Micro Power	6	Pinion Gear 303 S/ST	Winfred M. Berg
1	Winchester Disk Drive	ATAS I	8	12-Bit D/A Conv.,DAC811-AM	Burr-Brown
3	SMA to SMA Conn.	Astro Lab	15	IC 74ALS 02N	Various Suppliers
3	SMA to SMA Conn. (90°)	Astro Lab	20	IC74LS 670N	Various Suppliers
3	N to SMA Conn.	Astro Lab	4	Rotron Blower, Davilyn	Davilyn Corp.
5	SMA to SMA Conn.	Astro Lab	3	Pinion Gear "PG1"	Oliver Gear
3	N to SMA Conn.	Astro Lab			
3	N to N Conn.	Astro Lab			

Section 4
RF SYSTEMS

The Terrain Measurement system consists of several RF transmitters and receivers. These include 1) the X-band main transmitter and receivers for timing and data collection, 2) the L-band telemetry data link for digital communication between the two helicopters, and 3) the K_u-band Microwave Landing System (MLS) for position information of the two helicopters. At each data collection site, as well as the Buffalo area, frequency allocations are secured on a temporary basis for the multiple frequencies in the three bands.

4.1 MAIN TRANSMITTER

The main transmitter emits pulsed RF X-band signals including a direct signal to the receiver to set the system timing followed by the main signal pulse which is directed towards the ground to bounce signals up to the receiver. A functional block diagram of the transmitter RF system is shown in Figure 42.

4.1.1 Transmitter Functional Description

4.1.1.1 Transmitter Exciter. The transmitter exciter chassis generates the two pulsed RF signals. The first pulse (or pre-pulse) is at 8.8 GHz followed by the data pulse at 9.8 GHz. Each of the RF pulses originates from its own CW phase-locked oscillator. These oscillators are locked to a common 10-MHz rubidium source atomic reference. Each X-band frequency source puts out a CW signal at a power level of +10 dBm which passes through a directional coupler. The signal is taken from the -10-dB coupled port and passed to a variable attenuator to allow for the proper setting of the signal level entering a RF switch which modulates the CW signal into RF pulses. The RF switch is controlled with an ECL gate control pulse generated from the Mostek controller

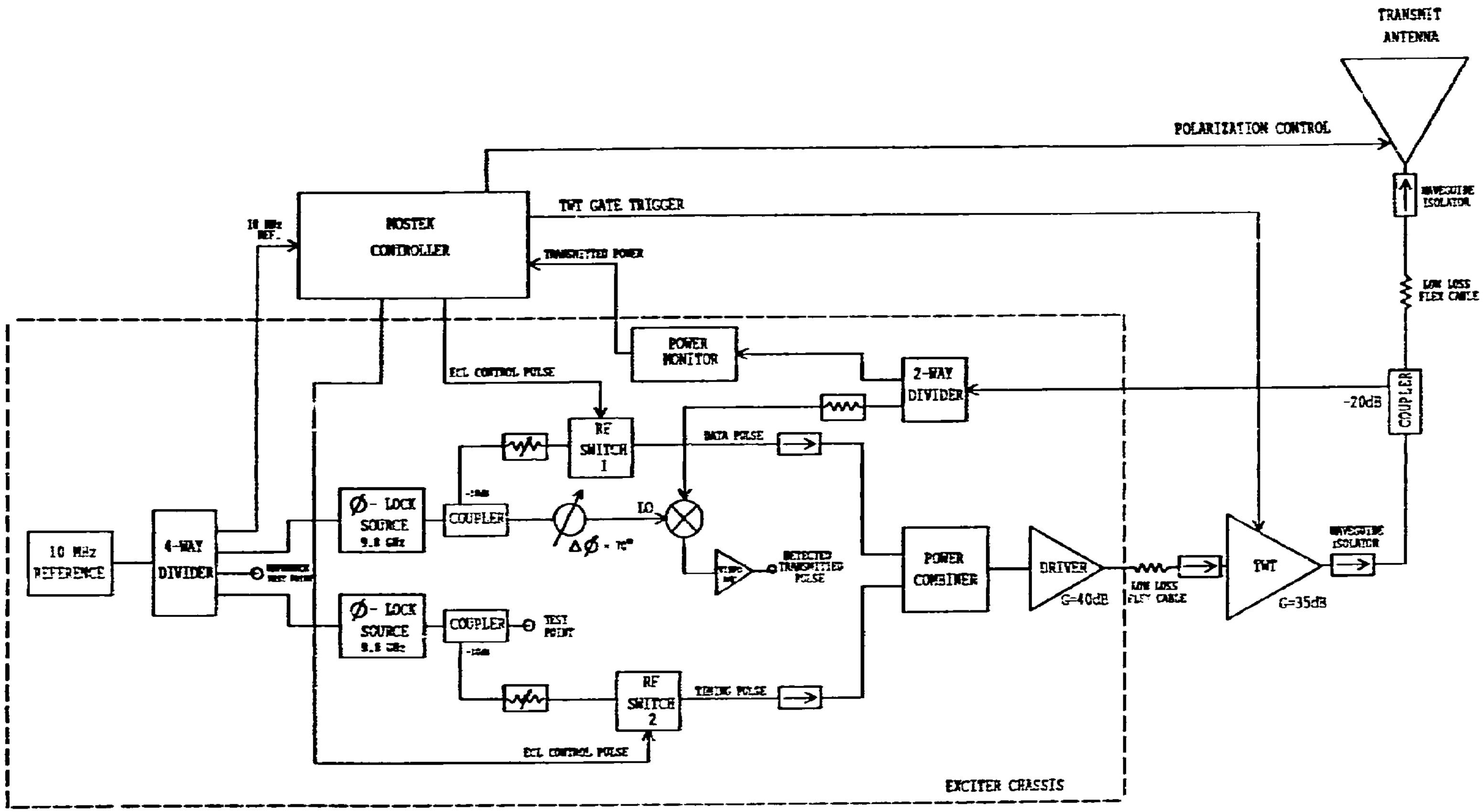


Figure 42. Transmit RF System

pulse board. The fast rise time of the RF switch (1 nanosecond) allows for clean pulse shapes down to a few nanoseconds. The paths of the two pulsed RF signals then enter a power combiner which feeds a common driver power amplifier at the output of the exciter chassis. These pulses are time separated by a 2-microsecond pulse separation interval so that there is no interference between the two pulses in the power combiner. The output of the exciter chassis at the driver amplifier is at the saturation power level of approximately +29 dBm. A short low-loss cable is used to connect the exciter output to the input of the traveling wave tube (TWT) final amplifier.

4.1.1.2 Final Amplifier (TWT). The final amplifier of the transmitter is a traveling wave tube (TWT) pulsed RF amplifier. An external trigger which gates on and off the grid voltage to the tube is generated in the Mostek controller and timed so that the RF pulses from the exciter chassis are roughly centered in the on-time of the tube. Thermal limitations of the TWT restrict the pulsewidth and pulse repetition frequency (PRF) to a duty cycle not to exceed 1 percent.

The rated gain of the TWT is 35 dB with a maximum power output of two kilowatts (+63 dBm). To maximize this output capability, the pre-amp driver on the exciter chassis is run at saturation providing a steady peak power level of +29 dBm to the input to the TWT. This in turn keeps the TWT just in saturation so that any small fluctuations in the exciter circuitry will not effect the overall output power of the transmitter.

In order to eliminate reflections in the transmitting system which will degrade the purity of the pulse shape, isolators are inserted at key locations in the circuit where VSWR is of concern. The output of the TWT is especially sensitive to impedance mismatches and therefore a special waveguide isolator designed for the center frequency of 9.8 GHz and capable of handling the peak power requirements have been incorporated to provide an overall output VSWR of better than 1.2:1.

A portion of the transmitted signal from the TWT output is coupled off through a 20-dB directional coupler and is fed back to the exciter chassis. This signal is then divided with half going to a power monitor to measure the RF power being transmitted and the other half to a pulse detection circuit. At the input to the pulse detector, 40 dB of attenuation is used to bring the high level signal level down to a desired level for the mixer which follows. The LO signal used for the mixer is coupled off of the 9.8-GHz source. This provides a coherent signal and a steady pulse waveform. A phase shifter in the LO line allows for the detected pulse to be adjusted to a peaked position as viewed on an oscilloscope.

4.1.2 Frequency Sources

The transmitted signal consists of two X-band frequencies. The system timing at the receiver is set up using the detected pulsed RF timing signal at 8.8 GHz. The main frequency of 9.8 GHz is used for reflected data collection. The 1-GHz separation between the two frequencies allows for filtering in the timing and data receiver channels of the other undesired signal respectively. The selection of the two X-band frequencies was based on the user density over the band for several geographical locations of possible test sites.

The X-band frequencies are generated using two phase-locked oscillators each of which is phase-locked to a common rubidium standard atomic clock. The center frequencies of the timing and data oscillators (8.8 GHz and 9.8 GHz respectively) can be mechanically tuned over a range of +/- 250 MHz in 50 MHz increments. Test points are available at the output of each source on the exciter chassis allowing for the frequencies to be monitored as needed.

4.1.3 Pulse Modulation

Pulse modulation of the CW X-band sources in the transmitter is controlled by the Mostek controller which generates the ECL gate pulses to the RF switches on the transmitter exciter chassis. A counter timer in the controller, referenced to the 10-MHz atomic clock, is used to create a train of pulses with adjustable width and duty cycle. This pulse train, referred to as the base, is passed through a programmable delay generator. This creates a deliberately skewed copy of the base which is referred to as the width. These two signals are then translated from TTL (transistor transistor logic) to ECL (emitter coupled logic) to take advantage of the ECL family's speed and rise time characteristics. Within the ECL logic the prepulse (PP) timing and main bang (MB) data control pulses are formed by the difference in time between the base and width signals. The base signal through other logic is also used to generate the trigger pulse for the TWT. The base signal's width becomes the spacing between PP and MB and the frequency of the base sets the PRI. Figure 43 is a timing diagram showing the creation of the PP and MB data pulse trains. Since the base signal's frequency and width, as well as the skew between the base and the width signals, are adjustable all of the resulting signals generated are adjustable.

The pulsewidth can be generated over a range of 2 nanoseconds to 13000 microseconds in 1-nanosecond increments. During data collection, the pulsewidth is usually restricted to a range of 6 to 60 nanoseconds with the pulsewidth changing as a function of azimuth angle. As an option, under software control, the pulsewidth can also be fixed for an entire geometry run. The timing channel receiver has a minimum pulsewidth requirement so that extra logic was added to limit the PP to a minimum width of 17 nanoseconds. The pulse detector circuit on the exciter chassis (see Section 4.1.1.2) is also used for calibration of the actual pulsewidth as a function of the commanded pulsewidth.

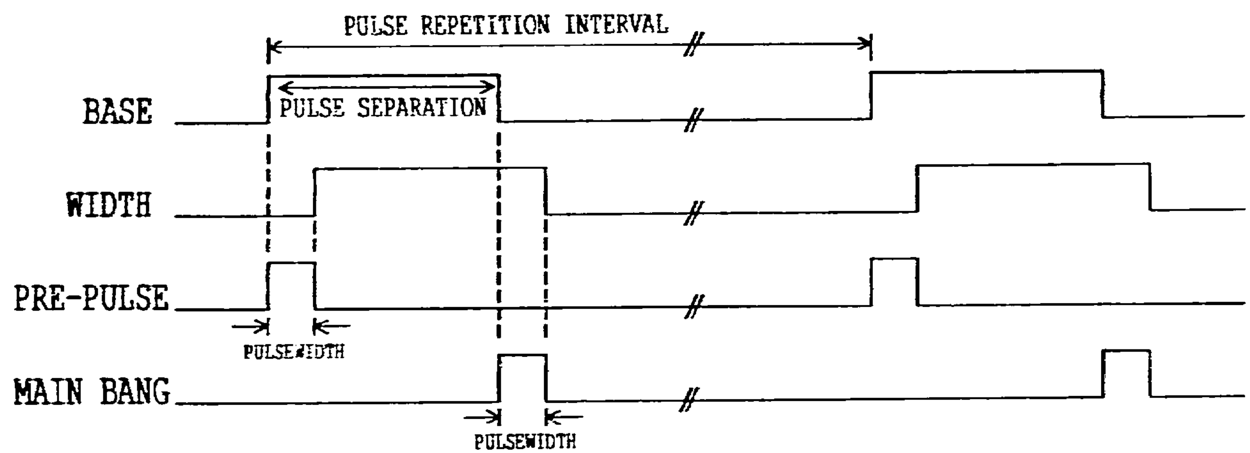


Figure 43. Pulse Generation Timing Diagram

The spacing between the pre-pulse and the main bang pulses is set nominally to 2 microseconds. This spacing is to ensure that any reflections of the timing pulse from the ground in the region of interest will be gone before the reflections from the data pulse are recorded.

The pulse repetition interval (PRI) is nominally set to 100 microseconds. This PRI was chosen to collect the data as quickly as possible so that the scan rate of the antenna would not effect the pointing angle that the data would be referenced to while keeping within the capabilities of the data acquisition system.

4.1.4 Power Output

The maximum power output of the transmitter at the final amplifier (TWT) has been measured at 2 kilowatts peak. The cable from the TWT to the transmitting antenna has a 3 dB loss lowering the transmitted power to 1 kilowatt peak (+60 dBm). A directional coupler at the output of the TWT provides a coupled off portion of the transmitted power to a power monitor located on the exciter chassis. The output of the power monitor is an analog voltage scaled to the input power level. This analog voltage is read by the Mostek computer through one of its analog input ports and displayed to the screen during data collection for the operator to monitor.

4.1.5 Calibration

4.1.5.1 Frequency. Calibration of the transmitted frequencies in the main transmitter is done at the time of set-up at a data collection site and is repeated as needed. The test points at each of the signal sources is connected to a frequency counter to measure frequency. In addition, the lock voltages of the phase-locked oscillators are checked. Voltages between 6 and 10 volts indicate a locked condition.

4.1.5.2 Pulsewidth. Due to the resolution of the delay lines used in the Mostek controller to generate the pulsewidth, the actual transmitted pulsewidths are not always exactly what is desired. A calibration of the commanded pulsewidth versus the actual pulsewidth is performed at the set-up time at a data collection site and is repeated as needed. The pulse, as viewed on an oscilloscope from the pulse detection circuit on the exciter chassis, is compared to the command input from the keyboard of the Mostek computer over the range of employed pulsewidths (usually from 6 to 60 nanoseconds) in 2-nanosecond increments.

4.1.5.3 Output Power. A measure of the output power level is taken at set-up time at a data collection site and is repeated as needed. Under computer control, the duty cycle of the transmitted pulse is set to 0.001 using a pulsewidth of 100 nanoseconds and a PRF of 10 kHz. The average output power is then measured using a digital power meter at the input to the antenna. Adding 30 dB (duty cycle factor) to the measured average power yields the peak output power measurement.

4.2 MAIN RECEIVER

The receiver used for data collection is a single conversion zero IF superheterodyne type receiver. Incoming pulses at 9.8 GHz are divided into I and Q components and mixed with an internal 9.8 GHz local oscillator to produce the coherent baseband video components that are digitized and recorded.

4.2.1 Functional Description

The receiver consists of six identical channels, one for each of the six monopulse outputs of the antenna. Figure 44 shows the block diagram of one of these six channels.

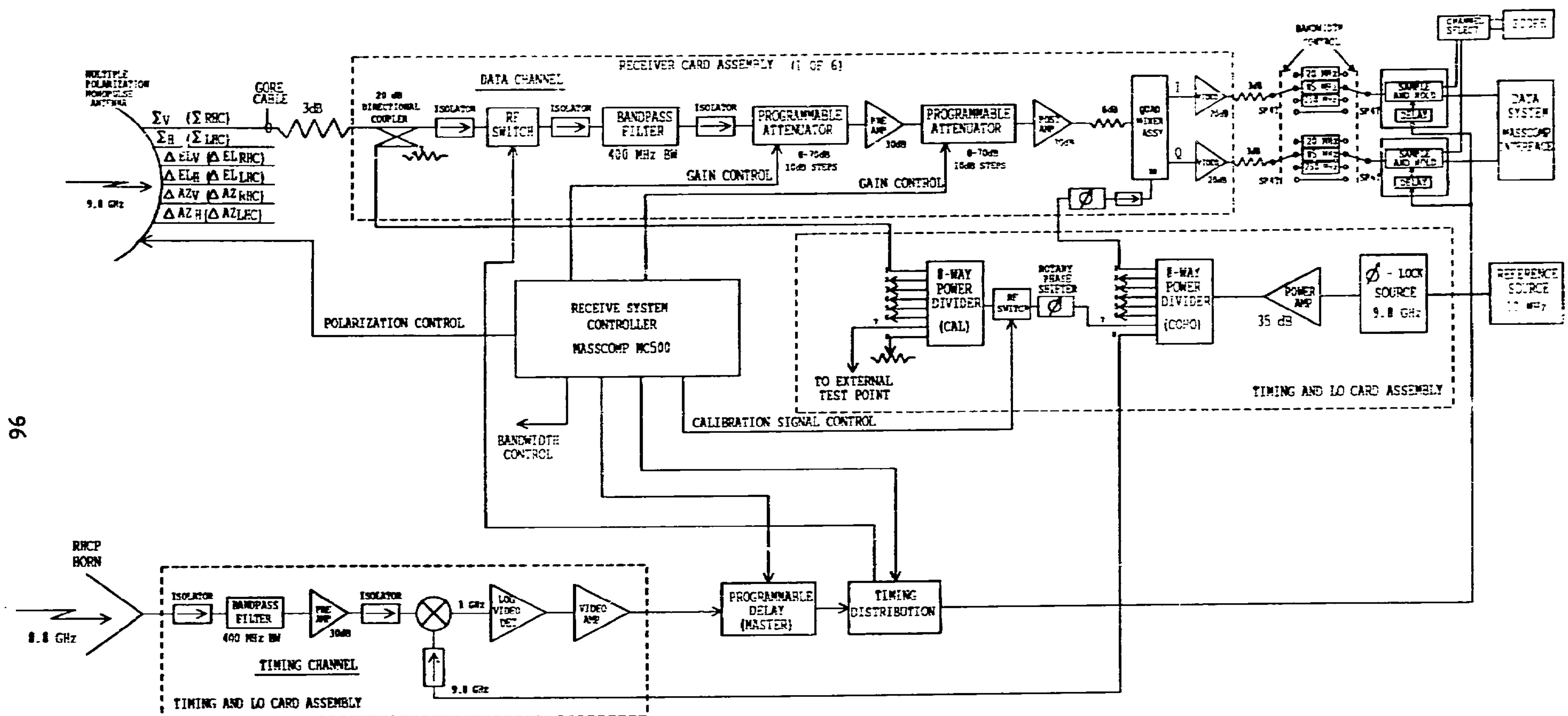


Figure 44. Receive RF System

The output of the monopulse antenna is fed via special flexible cables (see Section 4.2.6) to the receiver chassis mounted in the cargo area of the receive aircraft. The input to each receiver channel is through a directional coupler whose 20-dB coupled port is used to inject an internal CW calibration signal. Received signals then pass through an RF switch normally closed to allow inputs through. This switch is designed to gate out large direct signals in those cases where time separation does not allow the amplifiers to recover from a saturated state before the reflected terrain data signal arrives.

The next device in the signal path is the bandpass filter. This is a linear phase Bessel type of filter. The linear phase response of the filter inhibits pulse distortion and the 400-MHz bandwidth allows the the rise time characteristics required for the very narrow pulsewidths. The stopband response of -60 dB at +/- 1 GHz from the center frequency rejects the 8.8 GHz timing signal.

In-line coaxial isolators are used at the inputs and outputs of the switch and filter to improve the overall VSWR. Otherwise impedance mismatches inherent in these devices induce reflections in the signal path causing degradation of the pulse response of the receiver.

Following the filter is the first of two programmable attenuators. Each of these attenuators has a range of 70 dB in 10 dB steps and provides computer control of the gain of the receiver. The first attenuator is normally set to 0 dB in order to maximize the signal-to-noise ratio. In some cases, however, when very large signals are to be measured (such as direct beam measurements), this attenuator does come into use to prevent saturation of the first amplifier. The two RF amplifiers which follow are low noise, wide band devices which cover a frequency range of 6 to 12 GHz and provide a total of 60 dB gain. The second programmable attenuator is located between these two amplifiers and is used as needed to prevent the second amplifier from going into saturation. The output of the second or post-amplifier enters a quadrature mixer assembly through a 6 dB fixed attenuator. This attenuator adjusts the signal level to the mixer assembly input as well as provides a good input impedance match.

A block diagram of the quadrature mixer assembly is shown in Figure 45. The output of the final amplifier stage is input to a 90-degree hybrid 3-dB coupler. The signal is divided in half and delayed by 90 degrees in one leg so that the signals appearing at the output ports are of equal amplitude and 90 degrees out of phase (or in quadrature) to each other. Each of these signals then enters a balanced mixer where it is mixed with a common local oscillator source of 9.8 GHz. The result is baseband video I and Q components of the detected pulse.

After the quadrature mixer section, the I and Q video outputs are amplified using wide band video amplifiers (DC-500 MHz). These amplifiers have a fixed gain of 20 dB and a rated maximum output of +/- 1 volt. Most of these amplifiers, however, exceed their specifications providing greater than 1-volt output. To ensure that the input to the samplers does not exceed 1 volt (the LSB of the input A/D of the samplers is based on a 1-volt full scale), a 3-dB pad has been added at the output of the video amplifiers. This pad also provides for a better impedance match to the filter chassis.

The video filter chassis consists of a pair of SP4T coaxial switches and a set of 4 filter settings for each of the 12 video channels (I and Q of each of the 6 monopulse receiver channels). The four selectable positions are electronically controlled through the system computer and are used to control the video bandwidth and therefore the noise bandwidth of each channel. The four selections include low pass filters of 250 MHz, 85 MHz, 20 MHz, and a straight through line (no filter). The filter selection is based on the pulsewidth used in order to keep the noise bandwidth as low as possible without degrading the pulse response of the

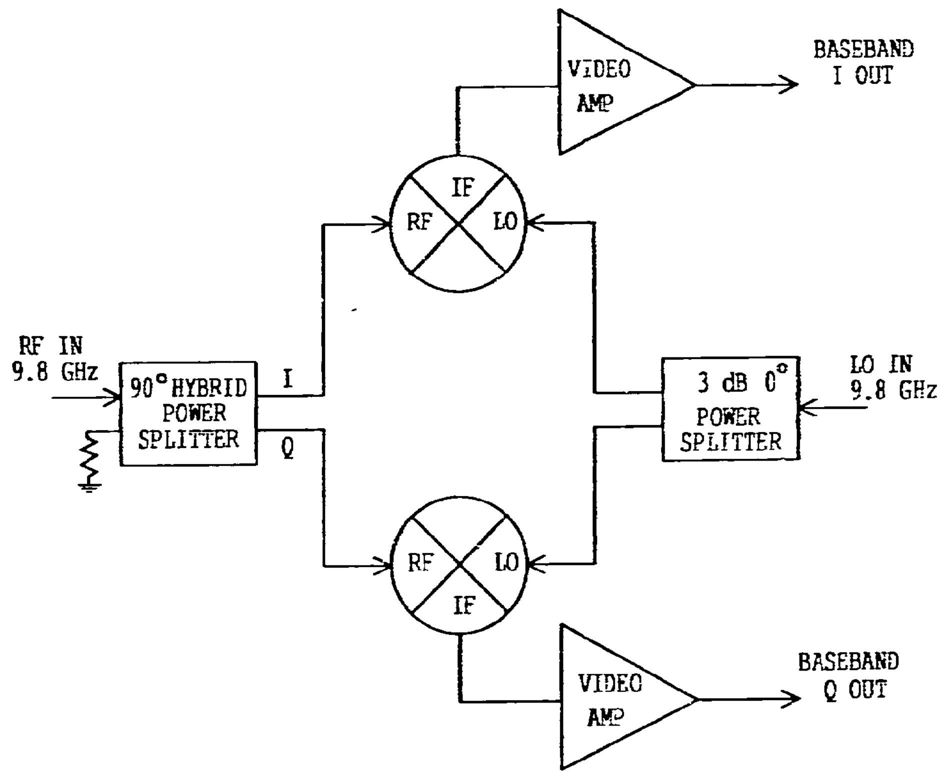


Figure 45. Quadrature Mixer Assembly

receiver system. The straight through line is used to measure the noise bandwidth of the receiver when it is limited by the input bandpass filter alone and also to check the receiver input noise figure.

The video signals then enter the sample and hold section. The input analog voltages are sampled and digitized based on a delayed trigger generated in the timing distribution. Internal A/Ds hold the last value sampled until they are read through the digital output port by the computer. The input analog voltages also appear at analog output ports of the sampler units which are viewed on an oscilloscope in real time. The oscilloscope can view only 2 of the 12 video channels at a time. Therefore, a channel view selection circuit was included. The 12 analog outputs of the samplers are connected to two SP6T switches. The channel to be viewed is selected electronically and one of the six ports is connected to the through line of the switch. The other 5 ports not being viewed are connected to an internal 50-ohm load. This internal 50-ohm load is important since the input sampling bridge of the sampler is very sensitive and must be kept properly terminated.

The internal calibration signal and the local oscillator signal for the mixer section are both generated in the receiver from a 9.8-GHz phase-locked oscillator locked to a rubidium reference source in the same manner as the transmitter. The output of this oscillator is amplified using a high power RF amplifier having a rated maximum output power of +27 dBm. The output is then divided through an eight-way power divider which supplies: LO lines to each of the 6 receiver quadrature mixer sections of the main receiver; one LO line to the mixer in the timing receiver; and one line for the calibration signal distribution. This calibration line goes through a rotary phase shifter which is electronically controlled to change the phase of the X-band signal 1.4 degrees every PRF. In this manner 256 consecutive samples of the calibration signal will trace out one cycle of 360 degrees. A high isolation switch (80 dB) at the output of the phase shifter prohibits the calibration signal from entering the front end input to the receiver when normal data collection is in progress. During the internal calibration, this switch is closed and the calibration signal is divided through an 8-way power divider. Six of the divider output ports feed the directional coupler inputs at each of the receiver channel front ends. One port is brought out as an external test point of the receiver chassis. One unused port is terminated.

4.2.2 Bandwidth

The front end bandwidth of the receiver is 400 MHz as determined by the bandpass filter at the input. These filters (one per channel) were designed to reject other signals, especially the 8.8-GHz timing signal, while still allowing for the minimum pulsewidths.

The video bandwidth is determined by the selection of one of three low pass filters at the video output. The three video bandwidths available (20 MHz, 85 MHz, and 250 MHz) are selected based on the pulsewidth and also determine the noise bandwidth thereby maximizing the signal-to-noise ratio.

4.2.3 Sensitivity

The sensitivity of the measurement system is determined by the signal-to-noise ratio. In order to maximize this it is important to keep the overall noise figure (and therefore the noise power) as low as possible. The equation that defines the system noise figure is

$$\text{Noise Figure} = 10^{*}\log F(t).$$

F(t) of a cascaded system is defined as:

$$F(t) = F(1) + \frac{F(2)-1}{G(1)} + \frac{F(3)-1}{G(2)} \;\ldots$$

and $G(n)$ = the gain of each stage (not in dB)

By placing a high gain low noise pre-amp near the input, contributions to the overall noise figure from subsequent cascaded stages is minimized. The computed noise figure for the main receiver referenced to the input to the flexible cables is 11 dB based on the component specifications.

Using the equation for noise power

$$P(n) = 10 \log KTBN$$

where $K = 1.38 \times 10^{-23}$
$T = 290° K$
$B = 400$ MHz
$N = 11$

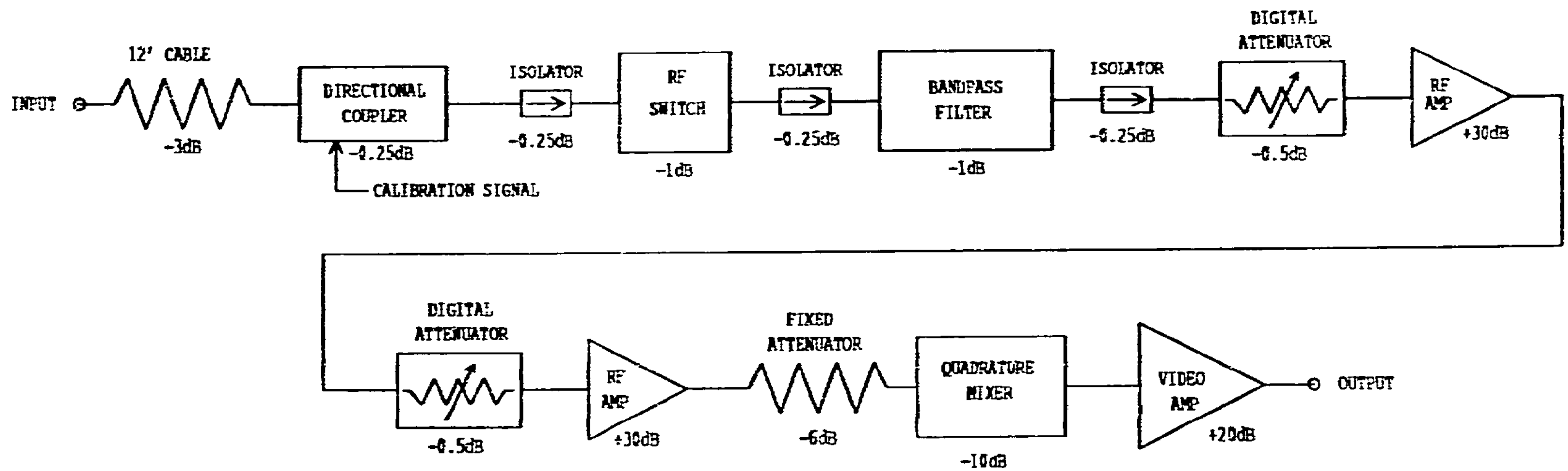
the computed noise power at the input to the receiver is -107 dBw (-77 dBm). Similarly for video bandwidths of 250 MHz, 85 MHz, and 20 MHz the computed noise power is -79 dBm, -84 dBm, and -90 dBm respectively. The input noise power has been measured for each of these bandwidths and has been within 2-3 dB of the theoretical predictions, an acceptable limit based on small differences in insertion losses of the many devices in the signal path. The method of noise power measurement used was to first monitor the output video signal level on a power meter with no input signal. A CW source at 9.8 GHz was then applied to the receiver input and the level adjusted until the output video signal doubled. The input CW source was then measured with a power meter as the equivalent noise power.

For a desired signal-to-noise ratio (SNR) of 10 dB, the minimum detectable signal (MDS) for single pulse detection at the widest video bandwidth of 250 MHz is -69 dBm. Since the receiver is coherent it is possible to utilize coherent integration of multiple pulses and lower the MDS while still maintaining the desired SNR thereby increasing the sensitivity of the receiver.

4.2.4 Receiver Gain

The overall gain of the receiver is computer controlled by the programmable attenuators in each of the receiver channels. The maximum available gain (when both attenuators are set to 0 dB) varies slightly from channel to channel due to small differences in the absolute gain (or loss) of the individual components in each channel. Figure 46 shows the theoretical overall maximum available gain of one channel based on the manufacturer's specifications.

The receiver gain is controlled by the programmable attenuators over a range of 100 dB. The pattern of increasing attenuator settings as shown in Table 5 is based on 1) maximizing the signal-to-noise ratio of the receiver for low signal levels, and 2) keeping the amplifiers out of saturation in the presence of high signal levels. After the first 30 dB of attenuation, the signals received will be sufficiently greater than the noise level so that keeping the first amplifier (or pre-amp) out of saturation is the key concern. With this gain pattern signal levels over a very wide range may be received without exceeding the output maximum of +13 dBm of the video amplifier. The gain control of this system is operator selected, as opposed to automatic gain control (AGC), therefore care must be taken not to expose the receiver to high signal levels that could overload the amplifiers.



MAXIMUM AVAILABLE GAIN = 57dB
NOTE: COMPONENT GAINS AND LOSSES BASED ON MANUFACTURER'S SPECS

Figure 46. Overall Receiver Maximum Available Gain

Table 5 RECEIVER GAIN PATTERN

Received Power (dBm)	Attenuator #1 Setting (dB)	Attenuator #2 Setting (dB)	Overall Gain (dB)	Output Power (dBm)
-80	0	0	57	-23
-70	0	0	57	-13
-60	0	0	57	-3
-50	0	0	57	+7
-40	0	10	47	+7
-30	0	20	37	+7
-20	0	30	27	+7
-10	10	30	17	+7
0	20	30	7	+7
+10	30	30	-3	+7
+20	40	30	-13	+7
+30	50	30	-23	+7
+40	60	30	-33	+7
+50	70	30	-43	+7

4.2.5 I and Q Orthogonal Phase Adjustment

In order to preserve the phase information of the detected signal, it is important that the phase difference between the I and Q channels be kept as close to quadrature as possible. Since all devices (especially at X-band) have some differences in phase delay on the signals that pass through them, the orthogonality of each channel was achieved by selecting those components that would yield an overall phase difference of 90 degrees +/- 3 degrees. To maintain the phase difference the outputs of the 90 degree hybrid divider and the power divider for the LO signal were connected to the mixers using right angle in-line coaxial connectors as opposed to semi-rigid coaxial lines. This eliminates the need to precisely construct coaxial lines of the same phase length. Further, once semi-rigid coaxial lines are bent and shaped to fit a needed installation, the overall phase length changes. The rigid construction of the right angle in-line connectors does not have this undesirable characteristic.

4.2.6 Phase Stability

For many applications of the data recorded it is necessary to know the absolute phase difference between the six monopulse channels. A calibration of the absolute phase difference may be done by injecting a common signal via a power divider to the six channel inputs. Then, using the I and Q components of the video data, the phase in each channel can be computed.

Normally the RF portion of a receiver is co-located with the receiving antenna using rigid (waveguide) or semi-rigid (copper covered coax) for short runs when necessary. The received signal is then mixed to a low frequency IF so that flexible cable runs will be lower loss and phase stability is not a problem. Likewise, the installation of the main receiver was originally planned to be in the cylinder area behind the dish antenna using small semi-rigid coax cables to connect the 6 monopulse output ports of the antenna to their respective receiver channels. Based on the performance of the stabilization system in the laboratory, however, it was anticipated that the elevation and azimuth drive motors might not perform acceptably under wind loading conditions with the additional weight of the receiver assembly on the antenna. For this reason the receiver was packaged and the chassis mounted on the floor of the helicopter behind the antenna. Since the antenna is in a scanning mode during static data collection, flexible cables were needed to connect the antenna outputs to the receiver.

Flexing of coaxial cables produces a phase shift in the signal due to the change in length of the center conductor and dielectric. At X-band frequencies and over a 12-15 foot run needed this phase change could be quite significant making it impossible to calibrate the absolute phase difference between receiver channels. For this reason special cables were selected based on their phase stability as well as low-loss characteristics. These cables (purchased from W.L. Gore and Associates) are designed to maintain their phase length to within 3 degrees while in a dynamic flexing and unflexing environment.

4.2.7 Receive Calibrations

Receive calibrations provide calibrations of various elements of the receiver equipment. These include antenna polarization, receiver absolute gains, I and Q channel gains and DC offsets, timing threshold, and delay settings for the sampler timing.

4.2.7.1 Receive Antenna Polarization. The polarization of the receive antenna is controlled by rotating dielectric polarization vanes within the circular waveguide sections of the antenna feed assembly. These vanes are turned using stepper motors which move the circular sections. Experience has shown that belt slippage of the motors caused degraded polarization ratios in the antenna ports. For this reason the belt arragement was modified to inhibit further slippage and the polarization vanes realigned. As a precautionary measure, the antenna polarization ratio is routinely measured as part of ground based calibrations to monitor possible polarization problems in the future. Since the belt modification and the incorporation of this calibration, the polarization ratio has remained stable. The procedure used to check polarization ratio included using a linear horn antenna with a cable at the ouput of a signal generator tuned to 9.8 GHz. With the horn held in a vertical position near one of the antenna feeds, the associated vertical and horizontal video output channel voltages were measured which determined the polarization ratio of that particular feed. This process was repeated at a horizontal horn position and for each of the five feed elements.

4.2.7.2 Receiver Absolute Gain. The absolute gain of the receiver channels is measured on a regular basis to determine the overall gain constant used in the data reduction process. An external source of a known amplitude is fed into each of the six channel monopulse inputs at a known power level bypassing the antenna. The output I and Q voltages are recorded and the overall channel gain computed.

4.2.7.3 I and Q Gain Differences. Each I and Q video channel may have slightly different gain values. To prevent these gain differences from affecting the data, a common internally generated signal is fed into each of the receiver front end inputs and the output voltages recorded. These voltages are then normalized to a common value and digital gain factors recorded which are later applied to the recorded radar data.

4.2.7.4 DC Offsets. During calibrations of the receiver, an internally generated CW signal is fed into each of the six receiver channels. A digitally controlled phase shifter increments the phase in the calibration signal line at the sample clock rate such that one set of 256 samples yields one full cycle. This full cycle of phase variations results in mean values in each channel that occur at their DC offset level. These offset values in each video channel are used to normalize out DC offset values in the recorded radar data.

4.2.7.5 Timing Threshold. As part of the ground based calibrations the input timing signal is cabled from the transmitter to the receiver through a variable attenuator bypassing the antennas. The timing signal is then attenuated until the trigger is no longer detected. The signal level is then increased until a sufficient signal to noise ratio allows for constant triggering. The threshold level is then set to a few dB above this level to assure constant and unperturbed timing trigger detections.

4.2.7.6 Sampling Time Fine Delays. Voltage controlled delays on each of the samplers allow for fine tuning the timing of the main trigger for sampling data. Adjusting these fine delays allows for careful time alignment of each of the I and Q channels. A common pulsed RF source is fed into the six receiver RF channels and the fine delay settings adjusted until the detected video pulses at the input to all 12 samplers are time aligned. These fine delay settings allow for alignment to less than one nanosecond.

4.2.8 Receive System Pulse Response

The antenna, microwave comparator providing the monopulse outputs, and the receiver including the baseband video circuits must provide sufficient bandwidth to assure proper reception of very narrow pulses. The antenna and the receiver were designed to have a bandwidth, greater than 400 MHz. To measure the pulse response of the system, data taken during direct beam (discussed in Section 4.4.1) data sets (that is when the antennas in the hovering aircraft are essentially pointed at each other) are analyzed. Figure 47 shows the recorded pulse received during one such data set. It is important that the pulse response of the system not degrade the expected response based on selected pulsewidth/bandwidth. Successive in-field direct beam data sets provide data to analyze the system pulse response for the pulsewidth/bandwidth combinations used.

4.3 TIMING RECEIVER

The timing receiver block diagram is included on the overall receiver block diagram of Figure 44. The timing pulse at 8.8 GHz is picked up by a small antenna mounted on the starboard side of the receive helicopter facing the transmit helicopter. This horn is circularly polarized (RHC) so that any transmit polarization used (vertical, horizontal, or right-hand circular) will allow the timing signal to be received.

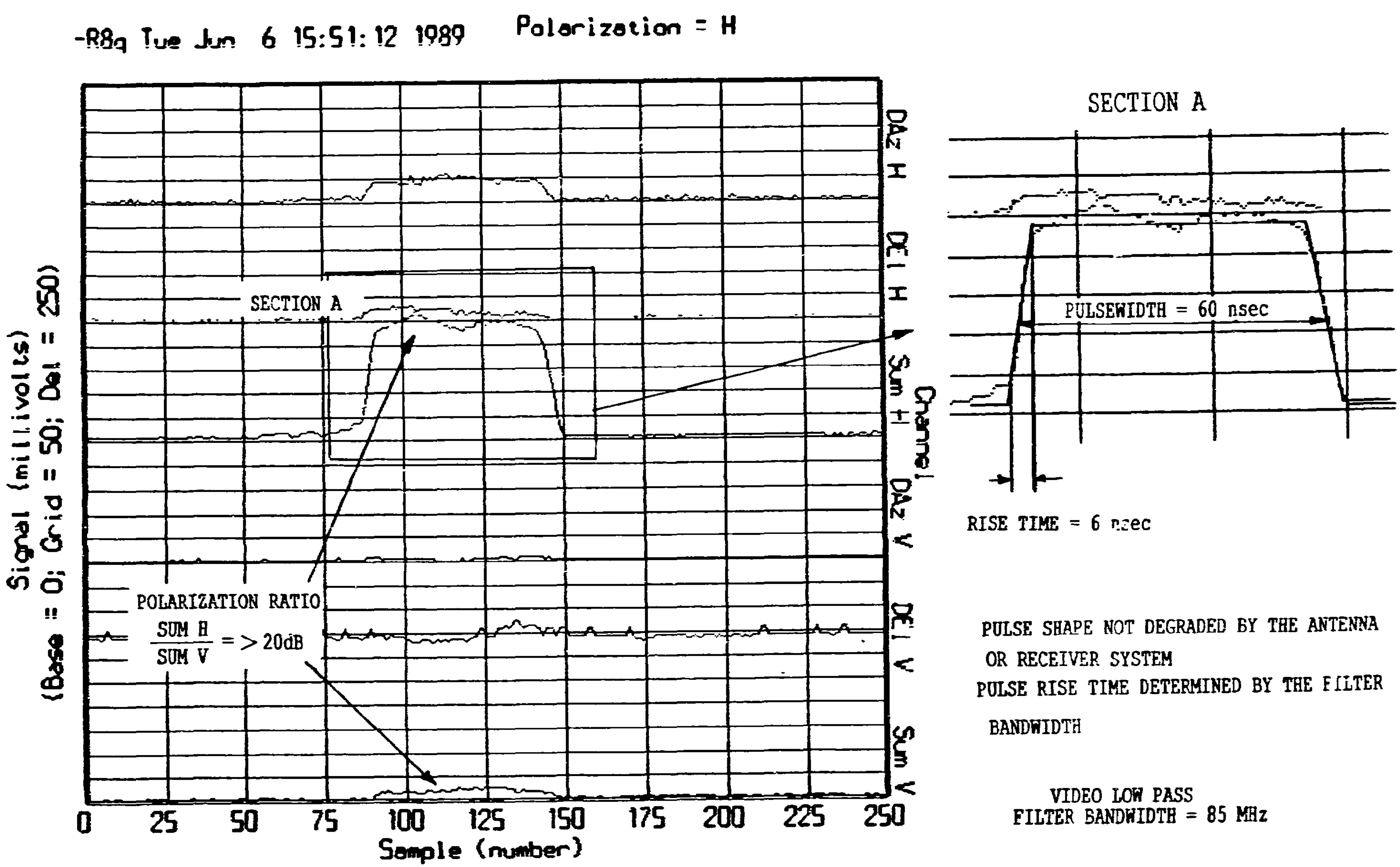


Figure 47. Receive System Pulse Response

The timing signal enters the receiver assembly through a bandpass filter with a center frequency of 8.8 GHz and a bandwidth of 400 MHz. The wide bandwidth allows for the narrowest of pulsewidths to be detected without degrading the rise time characteristic of the pulse. Since the system timing is based on the threshold crossings of this pulse, it is essential that the rise time be preserved. The stopband response requirements of the bandpass filter are the same as the main receiver, that is -60dB at +/- 1GHz from the center frequency. This prohibits the data pulse at 9.8 GHz from entering the timing receiver and interfering with the system timing. After the filter, the signal is amplified in a low noise amplifier. The signal is then mixed with the 9.8-GHz LO signal source used by the main receiver producing a 1-GHz IF frequency. This IF signal is fed to a log video IF amplifier. The detected video pulse output is further amplified using a wideband video amplifier and used to trigger the delay generator which controls the timing for the rest of the system.

4.4 OVERALL SYSTEM VALIDATION

Built in calibrations for the various portions of the RF systems have already been described in their respective sections. In addition to these, two methods of overall system validation (or end-to-end checks) have been implemented and are performed in a full scale data collection scenario so that all portions of the system are included. This includes not only the RF portions but also the stabilization systems, data recording systems, and aircraft positioning systems. The first is a direct beam data set which collects data while the two antennas are pointed at each other and measures the direct path power received. The second is a normal terrain data set that includes placing a test target calibrator (repeater) in the area that reflected terrain data are recorded.

4.4.1 Direct Beam System Validation

In order to validate the end-to-end system performance, a data collection scenario was devised which would allow for checks on the RF systems. This data set is performed in the static data collection mode with the two aircraft positioned at a fixed altitude and separation distance. The MLS provides the position information during this data set.

The transmit antenna is positioned at an elevation angle of zero degrees and at an azimuth of zero degrees relative to the plane between the two aircraft. This ensures that the receive aircraft is illuminated by the transmit beam. The receive antenna is scanned in elevation and azimuth nominally +/- 4 degrees around the same zero degree elevation and azimuth center reference. The scanning of the receive antenna ensures that the 2-degree beam of the receive antenna passes over the transmit source while allowing for errors in the station keeping of the two aircraft.

The transmitted pulsewidth is set to 100 nanoseconds and the polarization is changed at the end of each elevation scan in the same manner as the normal data collection procedure. Data are collected by the receiver at 1-nanosecond increments in time delay over 256 delays so that the resultant waveform that is recorded shows a very precise reconstruction of the transmitted pulse. From this, calculations can be made using position data and recorded radar data to compare the actual received signal power with predicted received signal power based on system parameters. While this technique does not calibrate any one portion of the system, it does show with all parameters given (such as transmitter power level, antenna gains of both the transmitter and the receiver, and receiver gain) how well the system is working and points out any system problems. The polarization ratios for each transmitted polarization can also be checked by comparing the recorded co- and cross-pol channels.

This type of data set is collected during each data collection session to ensure that the terrain data is valid and without system problems.

4.4.2 Test Target System Calibration

During the normal data collection session, a test target repeater may be added to the ground patch being interrogated by the receive scan pattern. This test target receives the transmitted pulse through a wide beam (50-degree) right-hand circularly polarized horn antenna. The circular horn allows for reception of any transmitted polarization with only a 3-dB penalty in the linear polarizations. The received pulse is then amplified and retransmitted using a vertically polarized antenna towards the receiver. As the receive antenna scans over the ground patch, it receives the test target repeater signal along with the reflected terrain signal. Since the test target signal has a finite signal level at its output, success in being able to pick the test target signal out of the recorded data will depend on the level of the reflected signal from the surrounding terrain.

Figure 48 shows the functional block diagram of the test target repeater. Ranges shown and used in the SNR calculations are comparable to a nominal 14 degree specular geometry. The amplifiers and oscilloscope shown in the figure are powered by a portable gasoline generator. The repeater station is manned by a member of the ground crew whose responsibilities include positioning of the test target antennas to cover the hovering transmit and receive aircraft respectively, operating the generator, and monitoring the retransmitted pulses from the test target to ensure uninterrupted operation during data collection. The test target operator is also supplied with a hand held VHF radio so that he can be in constant communication with other team members. This allows the test target to be turned on or off by the operator as desired by the test conductor depending on the data sets to be run.

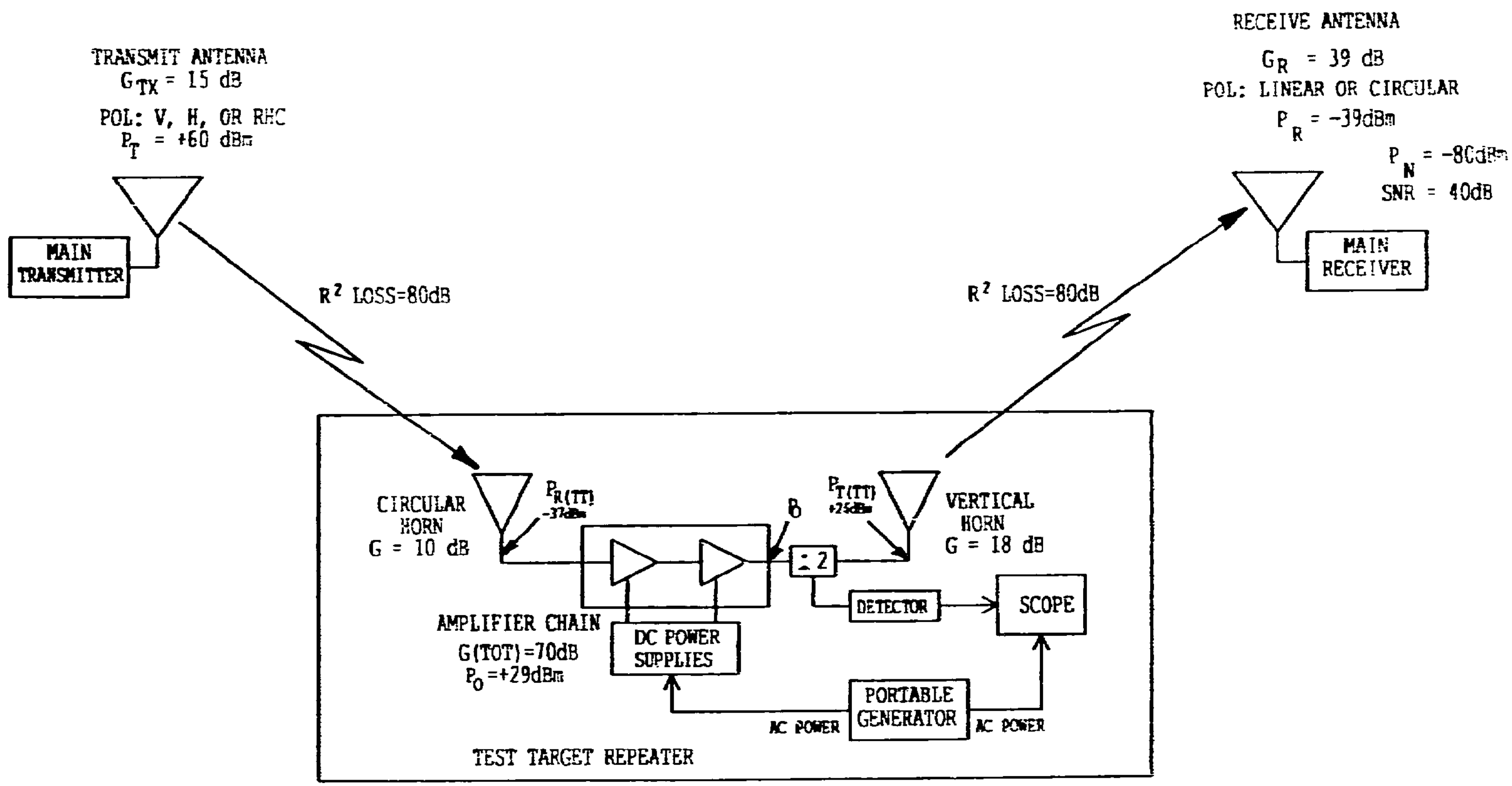


Figure 48. Test Target Calibrator Block Diagram

Placement of the test target is the most difficult aspect. The best results have been achieved by airlifting the test target operator and equipment by helicopter using the MLS to guide the aircraft to a desired location. It is best to place the test target at a position far enough removed from the specular region so that high level reflected data does not mask the test target signal. From Figure 48 it is shown that terrain reflections greater than 40 dB SNR will effectively mask the test target signal.

This signal, when used, will allow for an overall system check since the signal return will be of a predictable value. In addition, the elevation and azimuth angles at which it is detected should provide a check on the antenna control and stabilization system assuming the positioning of the target can be done with enough precision. Finally, the time of arrival of the test target signal can be used to check the system timing.

4.5 TELEMETRY

Ship-to-ship digital data communication is provided by means of a 1200-Baud L-band data link. Each terminal of the link consists of a separate transmitter and receiver using a common transmit/receiver antenna via a high isolation circulator. The transmit and receive frequencies are matched between the two terminals such that terminal #1 transmits on frequency #1 and receives on frequency #2 and vice versa for terminal #2. The two frequencies used (1525 MHz and 1454 MHz) are preset and fixed. No frequency agility is available. Therefore, careful consideration in the frequency allocation process is needed to ensure that other transmitters in the area do not interfere with the data link operation. In the receive portion of the link a limiter protects the receiver from high level signals. The 70-MHz separation of the two frequencies does not provide the needed rejection of the transmitted frequency in the co-located receiver at such high signal levels. To increase the selectivety a narrow bandpass filter is added at the receiver input. Digital data are transmitted over the link using a 1200-Baud modem. Figure 49 shows the data link wiring diagram.

Data passed over this link includes the following:

TRANSMITTER AIRCRAFT TO RECEIVER AIRCRAFT

Pulsewidth	6 bits
Polarization	2 bits
MLS Azimuth	16 bits
MLS Elevation	16 bits
MLS Range	16 bits
Carriage Return	8 bits

RECEIVER AIRCRAFT TO TRANSMITTER AIRCRAFT

Request data from TX	16 bits
Command Polarization	32 bits
Command Pulsewidth	32 bits

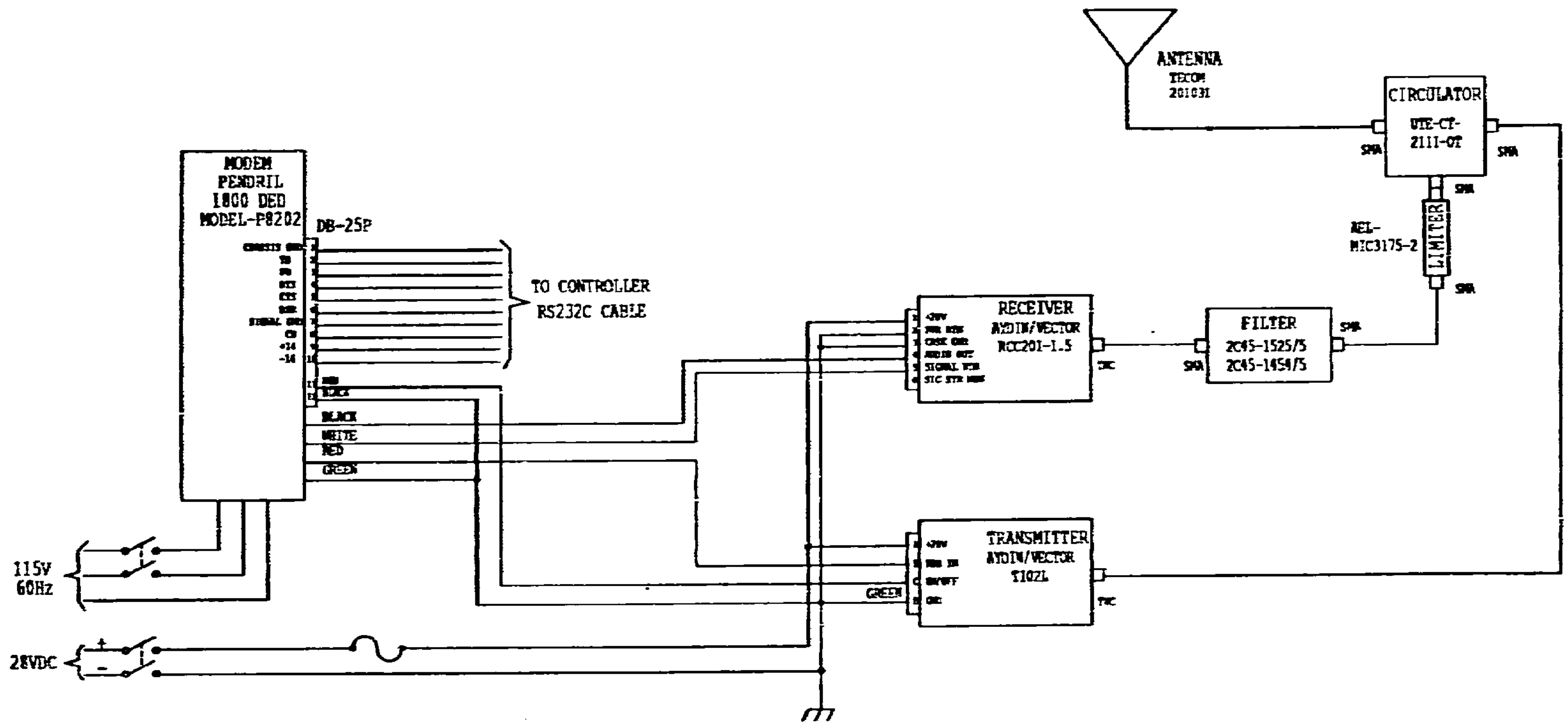


Figure 49. Data Link Wiring Diagram

Section 5

ANTENNA SYSTEMS

The terrain measurement system requires two very different antennas for the transmit and receive functions. The transmit antenna has a broad beam to illuminate the terrain over which data are to be collected while the receive antenna has a very narrow beam and is used to interrogate specific areas within the illuminated area. Both antennas are capable of using multiple polarizations. The transmitting antenna transmits one of four possible polarizations (vertical, horizontal, right-hand circular and left hand circular) while the receive antenna receives both the same sense and its orthogonal sense so that both co-pol and cross-pol data are received simultaneously. Both antennas were designed to be very broadband to ensure good pulse response characteristics for the very narrow pulsewidths to be used. The transmit antenna, however, is used for both the main data frequency of 9.8 GHz as well as the timing frequency of 8.8 GHz, making its bandwidth requirements even greater.

5.1 TRANSMIT ANTENNA

The transmit antenna is a corrugated conical horn antenna. The corrugated conical configuration has important characteristics which make it more desirable than a standard pyramidal horn. These include 1) the sidelobe levels are almost non-existent with a smooth beam skirt pattern, 2) the antenna patterns are symmetrical in both the E and H planes, and 3) the broadband characteristics are more easily realized. The beamwidth of the transmit antenna is 30 degrees nominal at the center frequency of 9.8 GHz with a slightly wider beamwidth at the timing frequency of 8.8 GHz. The gain of the antenna at both 8.8 GHz and 9.8 GHz is nominally 15.5 dB +/- 0.25 dB depending on the frequency and polarization. The input VSWR was measured to be <1.5:1. To further improve the VSWR and its possible effects on the transmitted pulse, a waveguide isolator was added at the waveguide flange input of the antenna assembly.

The transmit antenna polarization is changed by the rotation of a dielectric polarizing vane in the circular waveguide feed to the horn. This polarizing vane is rotated using a stepper motor to turn a section of circular waveguide within the rotary joint assembly. The stepper motor is controlled by a logic command from the computer to match a set of optical sensors placed every 45 degrees. Figure 50 shows a cross section view of the transmit horn assembly.

The horn antenna and the accompanying stepper motor and control circuits are packaged in a water-tight assembly which includes flanges and 1" diameter steel pins on either side for installation into the yoke of the antenna mount and stabilization system. It also includes an enclosed video camera package mounted on the underside of the antenna assembly. Figure 51 shows two views of the transmitter antenna system fully assembled. The video camera is cabled to a video recorder and monitor inside the transmit helicopter so that the area on the ground illuminated by the antenna can be viewed in real time by the operator as well as after the fact by playing back the video tape. When the lens controller of this camera is zoomed to the wide angle position, the field of view of the camera is roughly the same as the 3-dB beamwidth of the antenna thereby identifying the illuminated area. The overall size of the total antenna package is approximately 9"W x 20"L x 12"H and weighs approximately 25 pounds. When mounted in the stabilization system, it has positioning limitations of +10 degrees to -35 degrees in elevation and +/- 45 degrees in azimuth.

A comprehensive set of antenna patterns for the transmit horn antenna were taken on the antenna range at CHU Associates (the manufacturer). To cover the antenna response over the required bandwidth, patterns were taken at six frequencies (8.6, 8.8, 9.0, 9.6, 9.8, and 10.0 GHz) for cuts in both principal planes as well as every

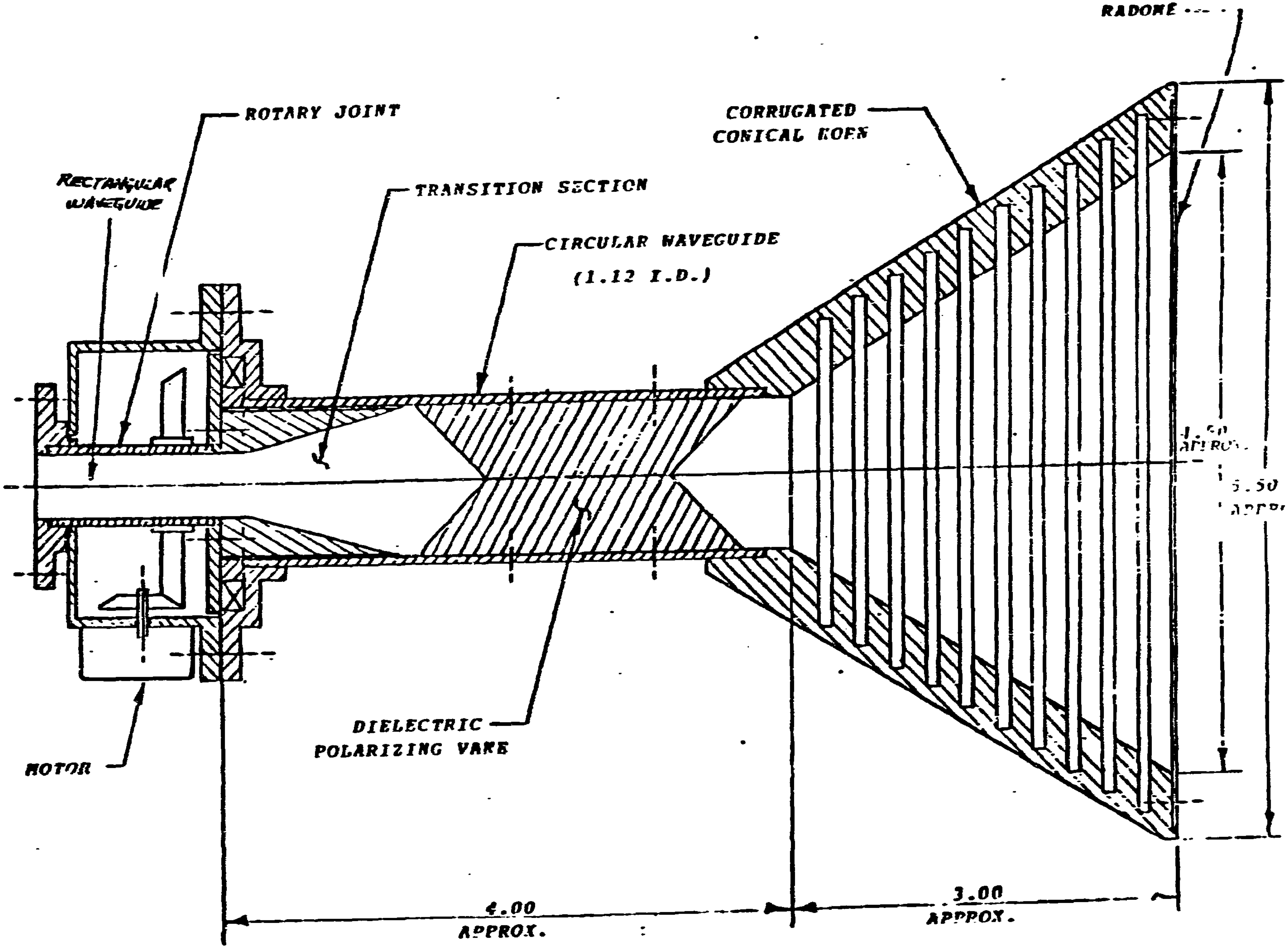


Figure 50. Cross Section of Multi-Polarized Transmitting Horn

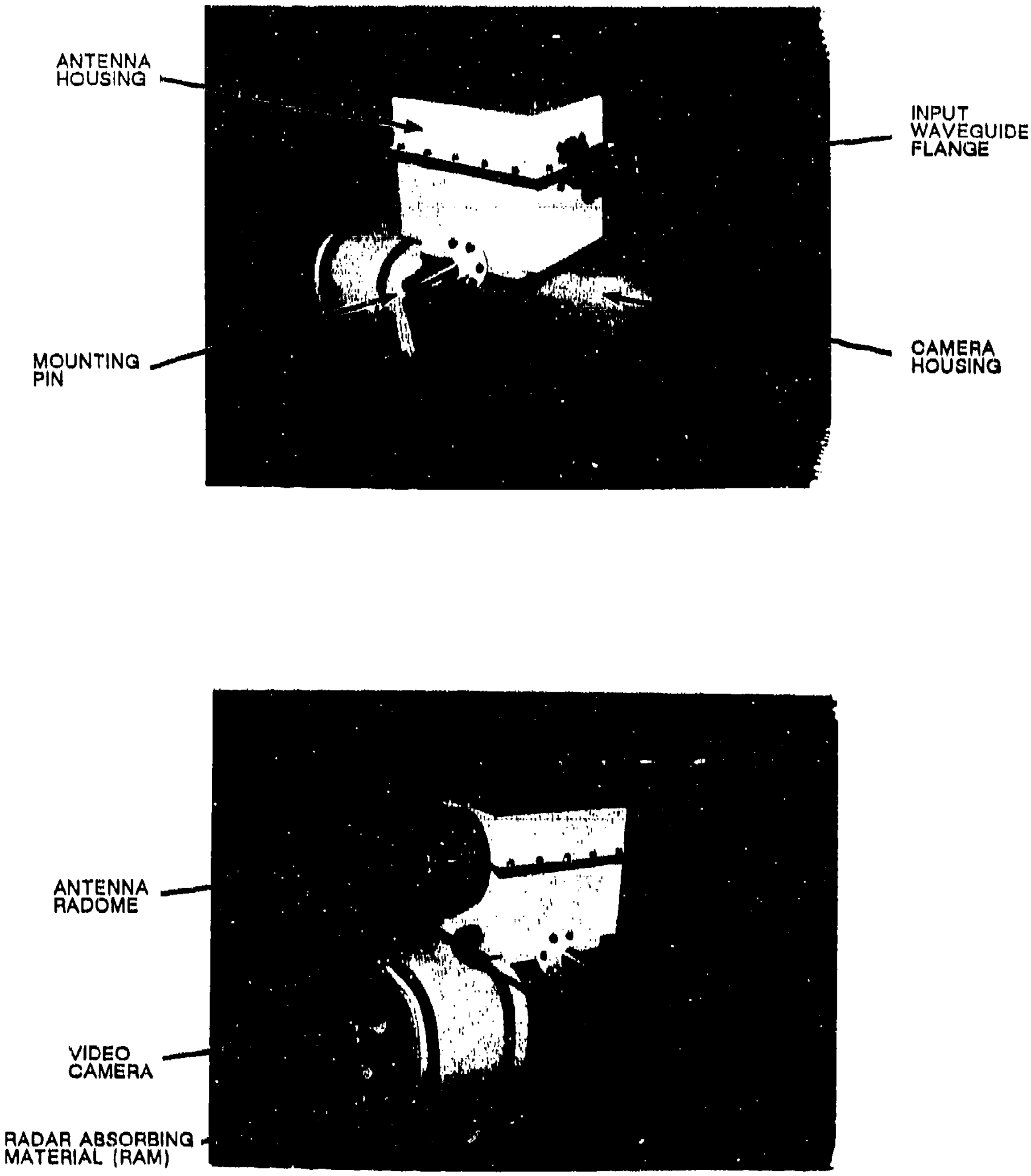


Figure 51. TRANSMIT ANTENNA ASSEMBLY

22.5 degrees in between. Also, cuts of the co-pol and cross-pol responses were recorded in order to measure the polarization ratio of the transmitted signal. Some representative patterns in the principal plane for vertical, horizontal, and right-hand circular polarizations at the main data frequency of 9.8 GHz are shown in Figures 52, 53, and 54 respectively.

5.2 RECEIVE ANTENNA

The receive antenna is a parabolic dish with a Cassegrain feed design. The overall dish diameter is 50" with an effective aperture diameter of 48" resulting in a 1.8-degree beamwidth. The subreflector of the Cassegrain feed is positioned using polyurethane rods to reduce the aperture blockage and thereby produce the best main beam and sidelobe response.

The antenna was designed for a center frequency of 9.8 GHz and a 400-MHz bandwidth to ensure the pulse response needed for the narrow pulses to be used. The gain of the antenna is nominally 39 dB at the center frequency with sidelobe levels 20 dB down. The peak difference channel gain is 35 dB with sidelobes 15 dB down.

The primary feed is a monopulse type feed providing sum and both azimuth and elevation difference channel outputs in both co-pol and cross-pol. It consists of four polyrod horns and one center conical horn. The center horn is used for the sum channel co-pol and cross-pol outputs alone. The four polyrods in a diamond feed configuration make up the two difference channels by using the upper and lower polyrods for the delta elevation channel and the left and right polyrods for the delta azimuth channel. Figure 55 shows the five element horn/polyrod primary feed configuration.

Behind the receive antenna dish is a cylinder which houses the primary feed and monopulse microwave comparator. The comparator provides outputs in both co-pol and cross-pol signals simultaneously for the sum and two difference channels for a total of six outputs.

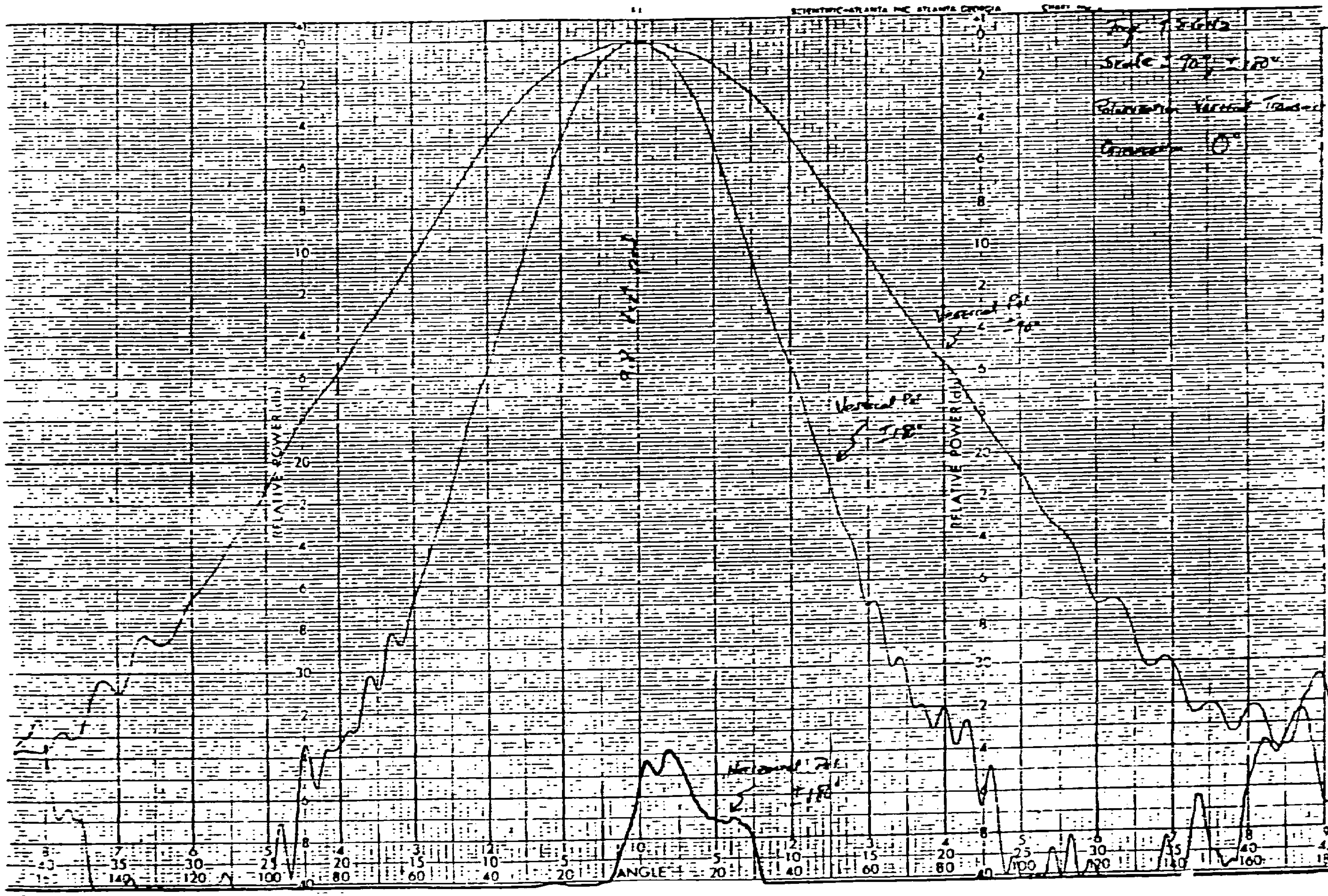


Figure 52. Transmit Antenna Pattern - Vertical Polarization

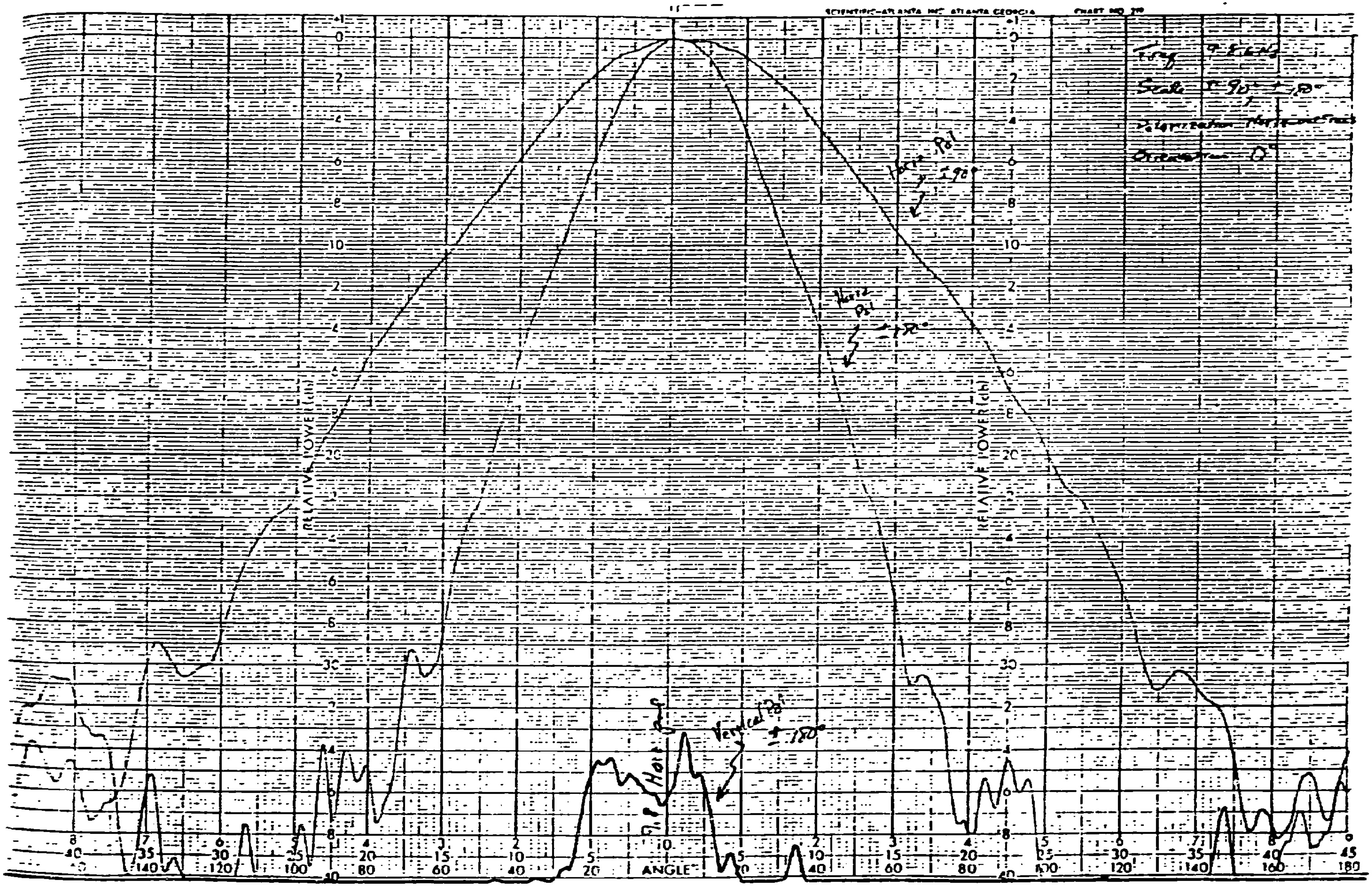


Figure 53. Transmit Antenna Pattern - Horizontal Polarization

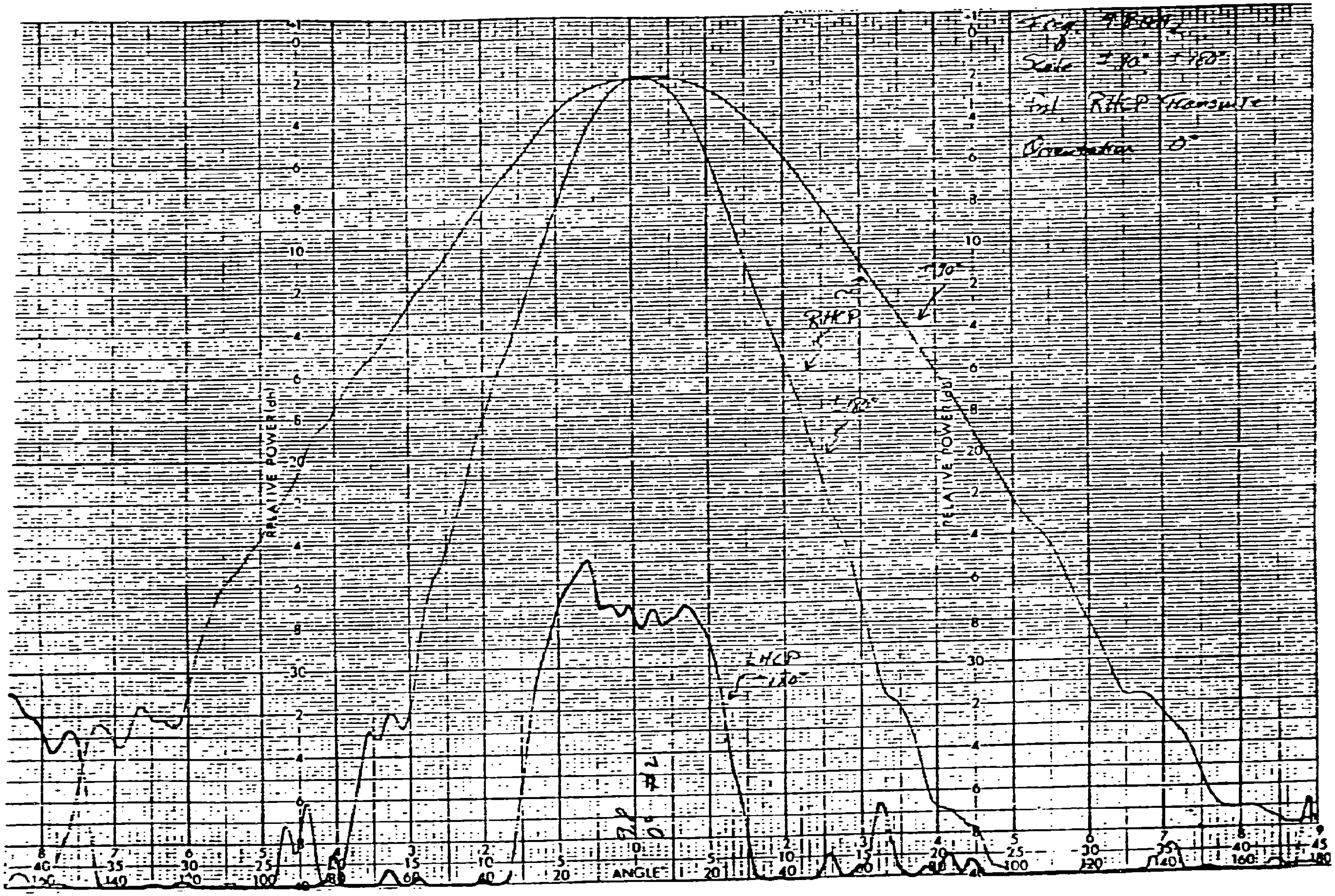


Figure 54. Transmit Antenna Pattern - Right-Hand Circular Polarization

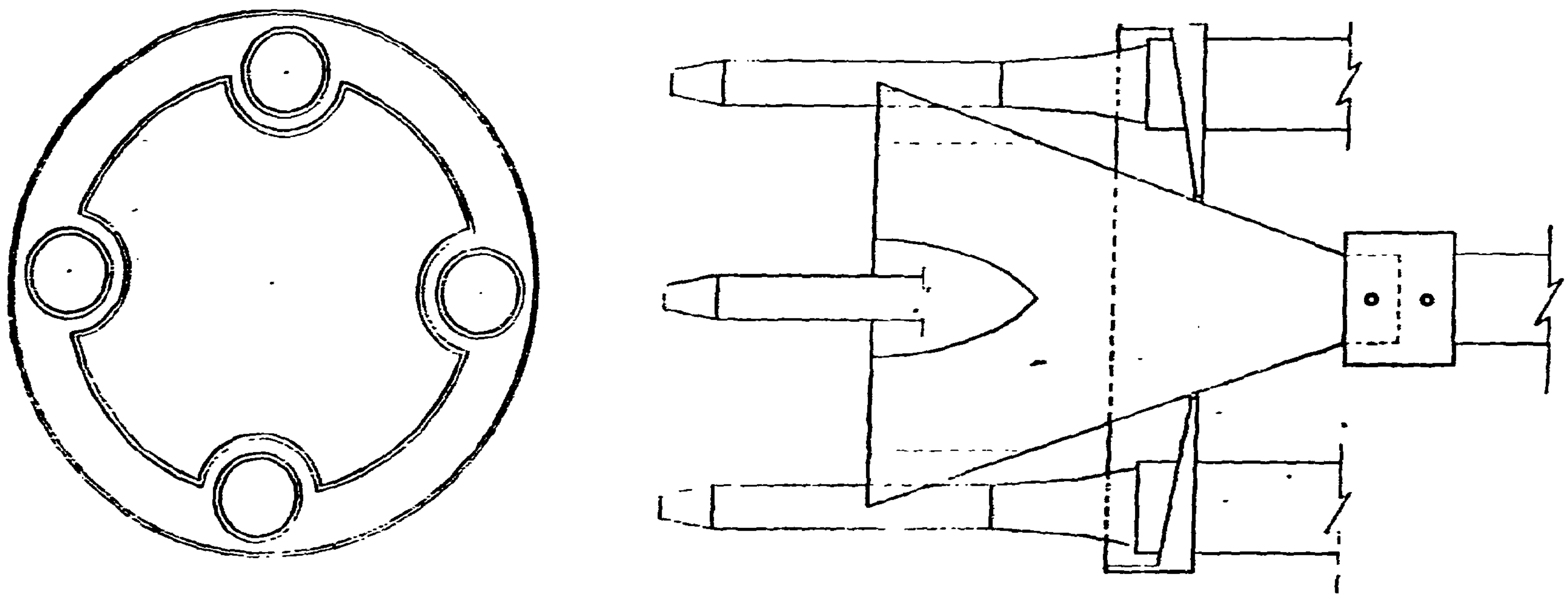
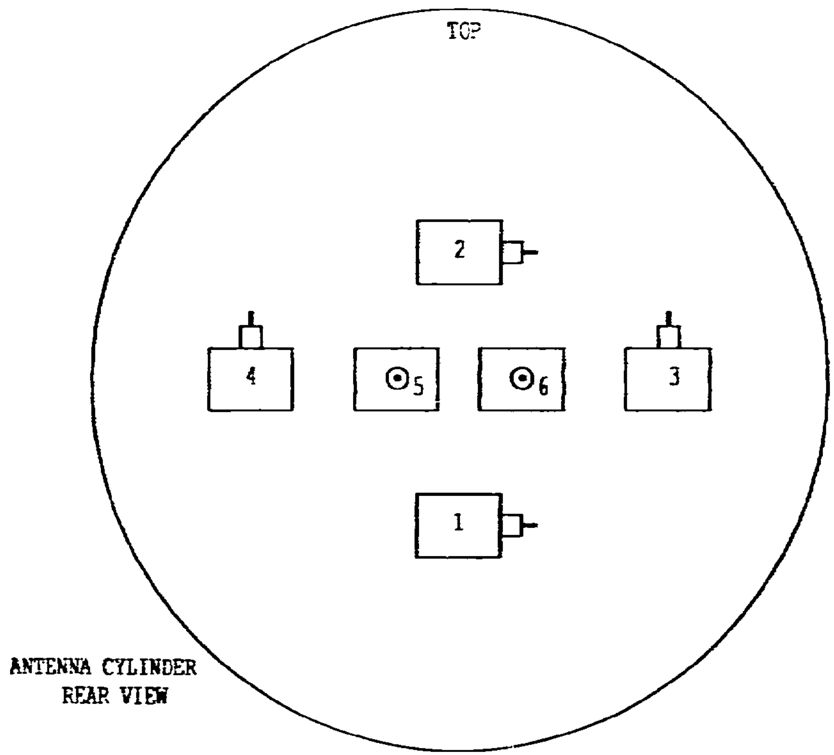


Figure 55. Receive Antenna System - Five-Element Feed

Figure 56 shows the 6 output ports and channels they represent. The received polarization is set to either linear or circular by the use of a polarizing dielectric vane in each of the five circular waveguide feed assemblies. The polarizing vanes are moved in 45 degree increments by the use of stepper motors which turn the circular waveguide sections containing the polarizing vane within a rotary joint assembly. Figure 57 shows the receive dish antenna and primary feed and microwave comparator assemblies.

A video camera is installed in the cylinder behind the antenna dish and a small cutout in the dish allows for viewing of the area where the antenna is pointed. This camera is connected to a video recorded and monitor within the receive helicopter for viewing in real time by the operator as well as after the fact by reviewing the video tape. When the lens controller of this camera is zoomed to the telephoto position, the field of view of the camera is roughly the same as the 3 dB beamwidth of the receive antenna. This allows an observer to identify the type of terrain patch over which the data are being received. The antenna assembly includes flanges on either side of the cylinder with 1" diameter steel pins for mounting in the yoke of the stabilization system. The assembly weighs approximately 100 pounds. When mounted in the stabilization system it has scan restrictions of +6 degrees to -32 degrees in elevation and +/- 30 degrees in azimuth.

A comprehensive set of antenna patterns for the receive antenna were taken on the antenna range at Chu Associates. These included co-pol and cross-pol data for all six output ports in both principal planes as well as every 22.5 degrees at three frequencies (9.6, 9.8, and 10.0 GHz). Some representative patterns at 9.8 GHz of the principal plane cut for vertical, horizontal, and right-hand circular are shown in Figures 58, 59, and 60 respectively. Some of the characteristics these patterns show include 1) the 3-dB beamwidth of 1.8 degrees, 2) the sum channel sidelobe levels 20 dB down, 3) sum-to-difference channel peak gain difference of



PORT MAP

PORT NUMBER		LINEAR	CIRCULAR
1	Δ Az	HORIZONTAL	LHCP
2	Δ Az	VERTICAL	RHCP
3	Δ El	VERTICAL	LHCP
4	Δ El	HORIZONTAL	RHCP
5	Σ	HORIZONTAL	RHCP
6	Σ	VERTICAL	LHCP

Figure 56. Receive Antenna Output Port Designations

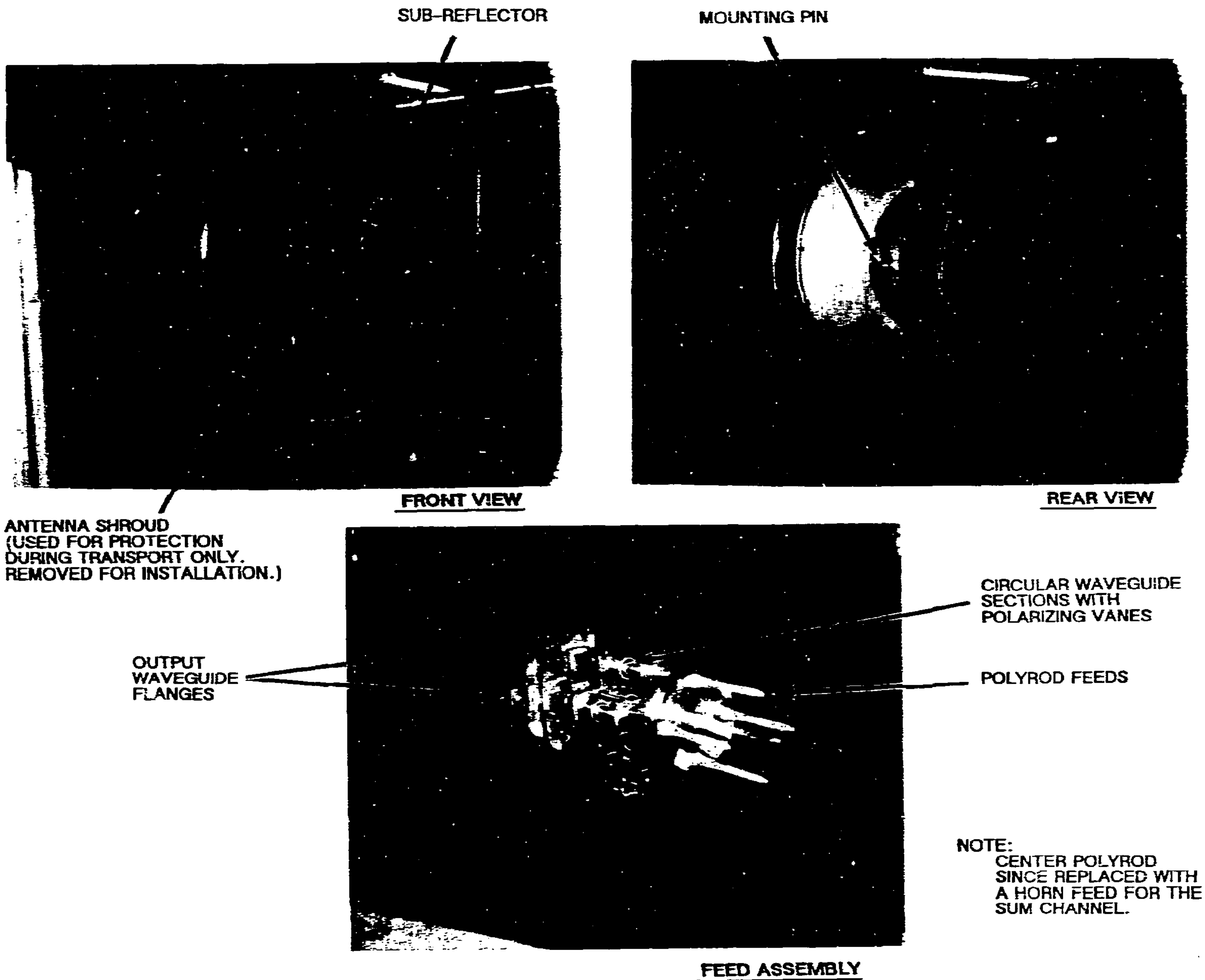


Figure 57. RECEIVE ANTENNA ASSEMBLY

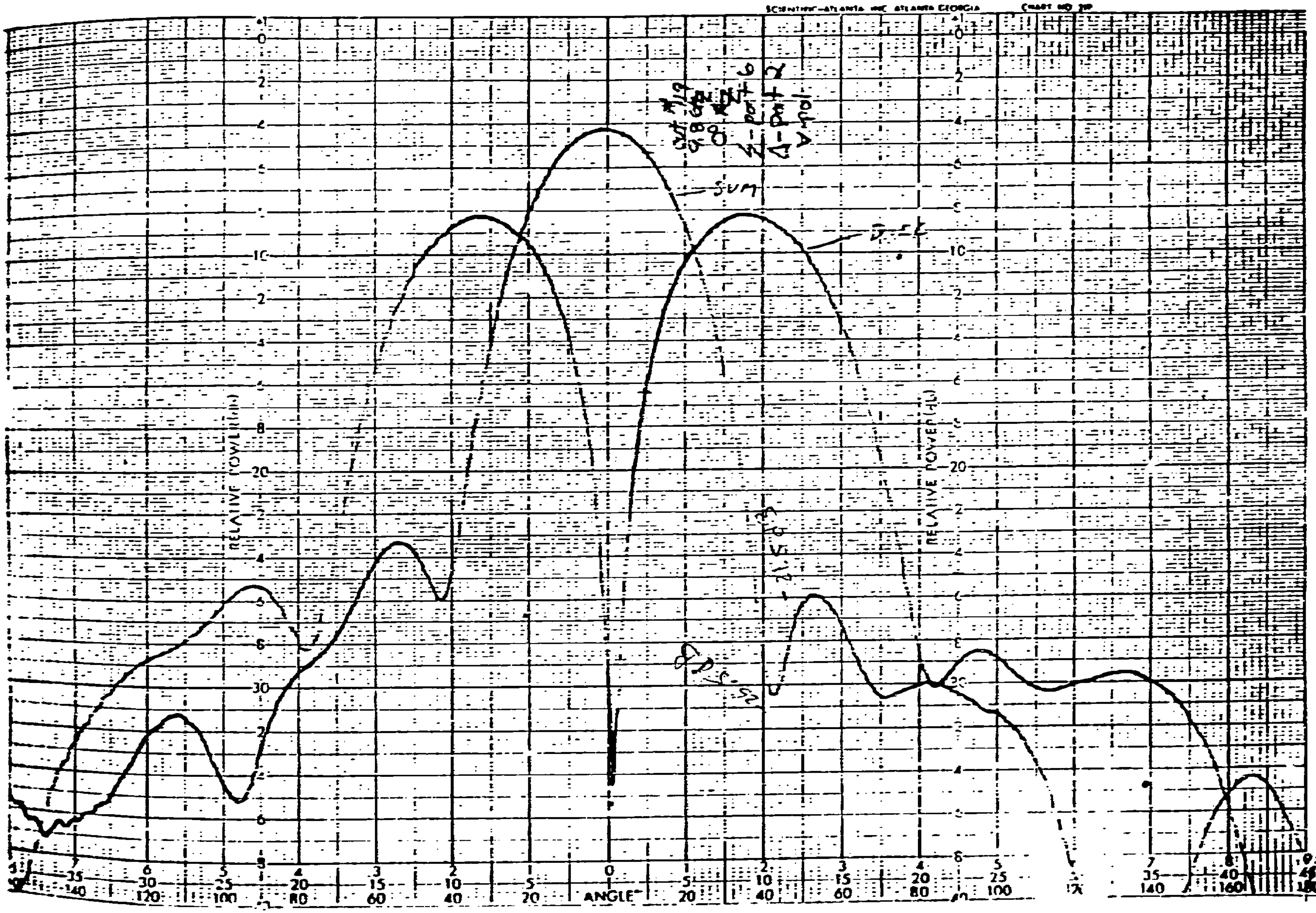


Figure 58. Receive Antenna Pattern - Vertical Polarization

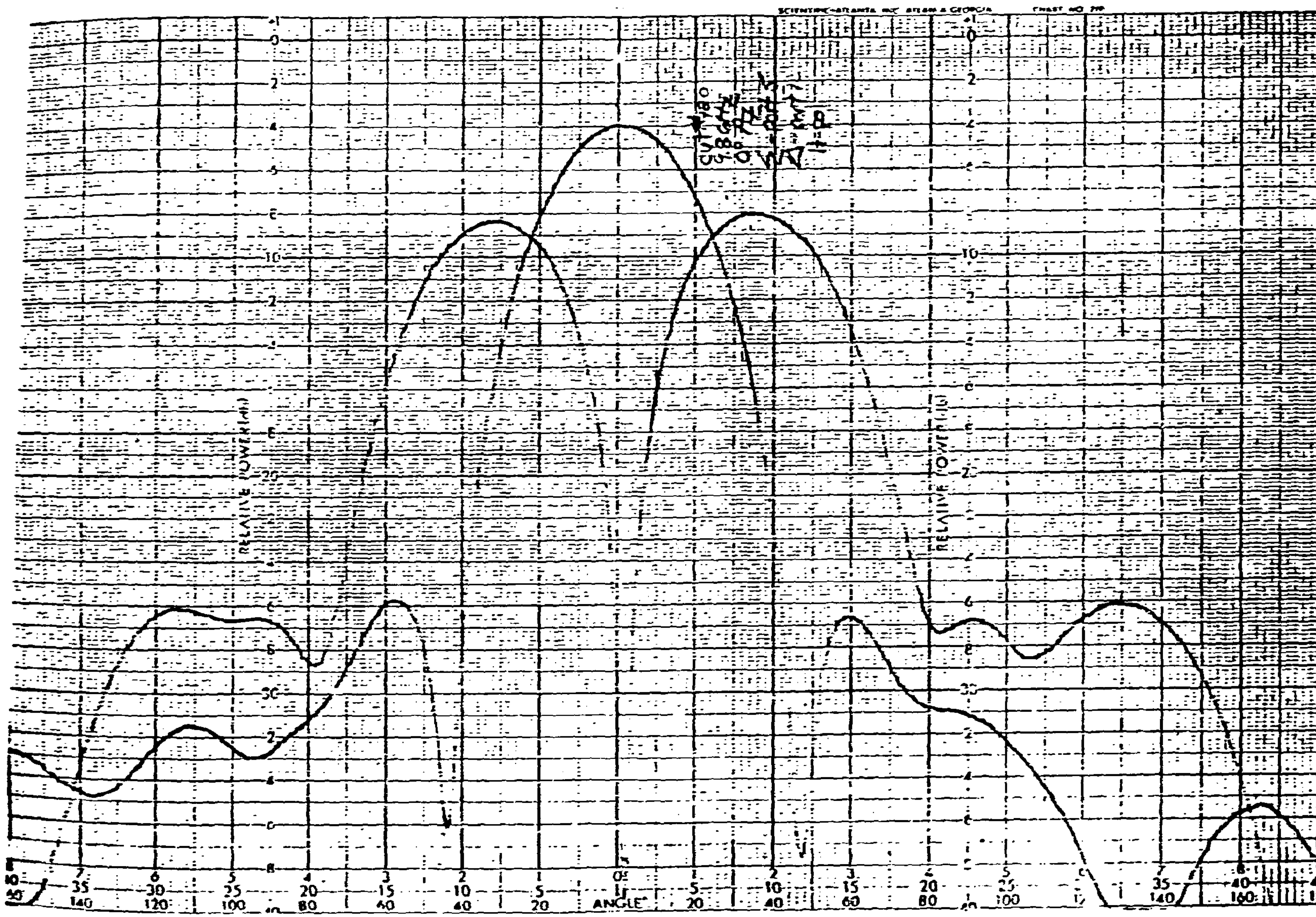


Figure 59. Receive Antenna Pattern - Horizontal Polarization

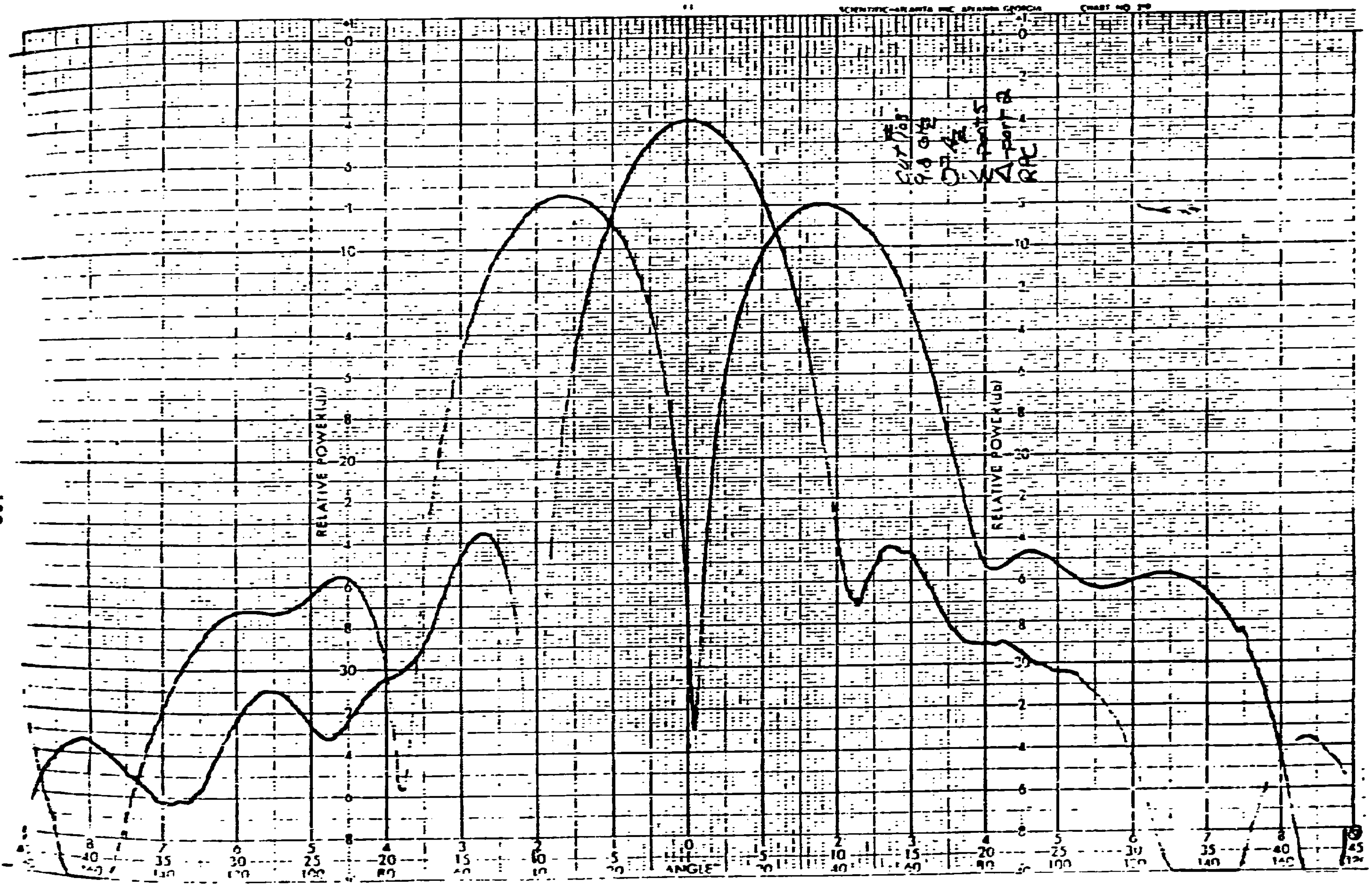


Figure 60. Receive Antenna Pattern - Right-Hand Circular

4 dB, and 4) the difference channel null position and depth of 30 dB.

Section 6
STABILIZATION SYSTEMS

Two stabilization systems, one for the transmitter and one for the receiver, were designed and built for the Terrain Measurements program by D^{2}C, San Diego, CA. These systems provide for both the stabilization of their respective antenna systems from external motions as well as act as antenna positioners. Both systems follow the same basic design philosophy with some additional antenna scanning capability added to the receive system. The stabilization systems are both four-axis gimballed systems which are (from outer to inner) pitch, roll, azimuth, and elevation with each axis servo controlled. Each system is comprised of four major sub-assemblies: a 4-axis mechanical gimbal, an antenna control unit, a joystick controller, and servo amplifiers for each axis. The systems were designed to position and space stabilize the transmit and receive antenna assemblies in the environment of two hovering UH-1H helicopters.

6.1 CHARACTERISTICS

The stabilization system is based on maintaining the antenna position and pointing angles in the environment of a moving platform which introduces into the system undesired angular movements in three axes: pitch, roll, and yaw. In addition, the positioning of the antenna pointing angles must be controlled in two axes: elevation and azimuth. The pitch and roll motions are compensated in their respective servo loops. The yaw motion is combined with the azimuth control in a single axis. Sensing of aircraft motion is provided to the stabilization system in several ways. A vertical gyro is mounted on the antenna platform which provides angle errors in two dimensions from vertical, i.e. pitch and roll, to the servo motors to drive the platform back to a vertical position. In addition, rate gyros for both pitch and roll mounted near the aircraft centerline provide rate information of the external source (aircraft) to the servo loops. Yaw motion is provided by the aircraft's directional gyro.

The major components of each system vary due to the more stringent requirements of the receive system. The overall design of the gimbal systems for both the transmit and receive systems are the same. The main difference lies in the gear ratios in the respective systems with the receive system having higher gear ratios to handle the larger torques and loads.

The antenna control unit of the transmit system is designed to drive the antenna to a fixed position and hold that position by correcting for external inputs due to aircraft motion or wind loads. The antenna control unit for the receive system on the other hand is much more complex. It consists of a commercial antenna control unit (ACU-6) from Electro-Magnetic Processes, Inc., Chatsworth, CA (EMP). This digital unit's control software was modified to fit the scan requirements of the Terrain Measurements Program. These software modifications included a variable number of elevation scans at each azimuth, a modified dead time at the end of each azimuth step to allow the system to settle before the next elevation scan begins, and front panel manual inputs to the loop gain constants, calibration zero positions, and compass correction.

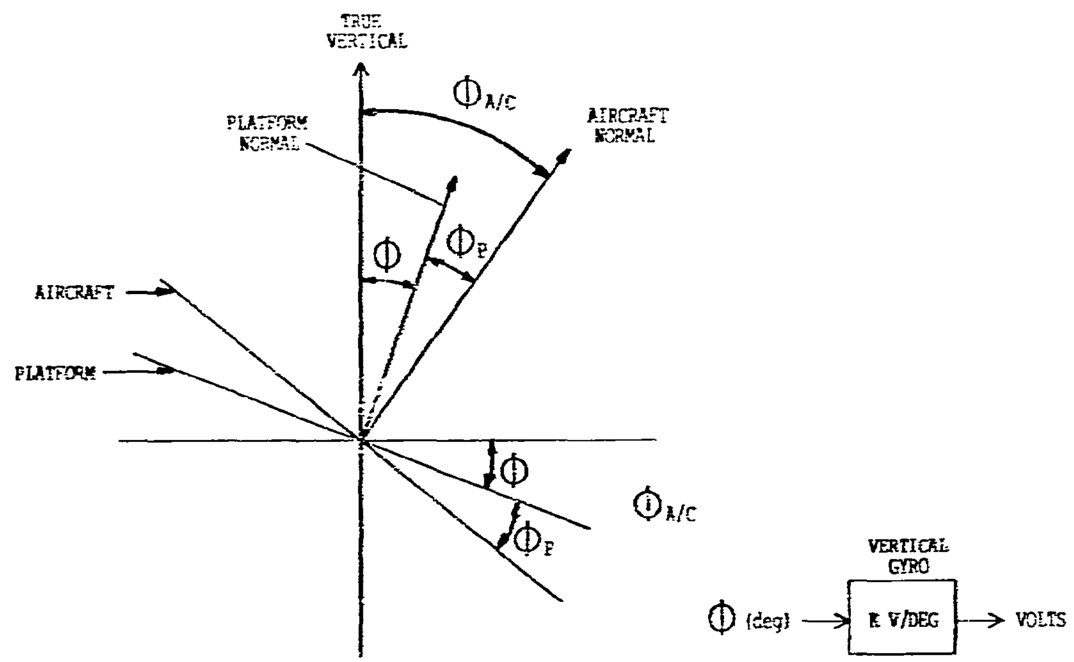
The servo amplifiers for pitch, roll, and elevation are the same for both the transmit and receive systems. Due to the higher torque requirements especially under wind load conditions, Calspan had to replace the azimuth servo amplifier in the receive system with a higher current rated amplifier. In addition, the new servo amplifier had to be run off of its own power supply since the power supply for the other servos was current limited for the higher current amplifier.

The joystick controller for both systems is identical. It is a rate control, i.e., the larger the deflection of the control the faster the antenna moves. In both systems when the joystick is utilized it takes the place of the rate output from the antenna controller.

6.2 PITCH AND ROLL

Pitch and roll motions induced into the antenna platform position are a result of the mechanical connection between the aircraft and the platform. When the aircraft induces a pitch (or roll) motion into the system the platform initially follows. This causes an off vertical angle in the platform position that is sensed by a vertical gyro mounted on the platform. Servo motors are then activated to counteract the angular error by driving the platform back to vertical. This causes an angle difference between the aircraft normal and the platform normal. Figure 61 defines the angles described above. The aircraft angle off vertical in this diagram may represent either pitch or roll motion.

Control loops are the same for both pitch and roll as well as for both the transmit and receive aircraft with the exception of the gear ratios. The transmit pitch and roll gear ratios are both 800:1. The receive pitch and roll gear ratios are 960:1 to account for the higher torque requirements. Figure 62 shows the block diagram of the pitch and roll axis servo loop. External inputs to the system which result in off-vertical angle errors may come from aircraft motion or from external loading (e.g. wind loads) on the platform itself. The angular error sensed by the vertical gyro causes a control voltage to be applied to the compensating servo mechanism. Output from the motor in the form of tachometer feedback provides the damping input to control oscillation in the servo control loop. Because of the mechanical connection, the platform angle-off-vertical due to aircraft motion will always lag the aircraft angle-off-vertical. In order to minimize this lag and maintain the required angle accuracy in pitch and roll, angular rate information of the aircraft motion is provided via two rate gyros each mounted in their appropriate pitch or roll axis on the airframe. These rate signals provide a predictive input to the servos to help minimize lag errors.



$\Phi_{A/C}$	(deg)	ANGLE BETWEEN VERTICAL AND A/C NORMAL - CHANGES WHEN A/C PITCHES OR ROLLS
Φ_P	(deg)	ANGLE BETWEEN A/C NORMAL AND PLATFORM NORMAL - CHANGES WHEN MOTOR DRIVES GEARS WHICH MOVE THE PLATFORM WITH RESPECT TO THE A/C
Φ	(deg)	ERROR BETWEEN THE PLATFORM VERTICAL AND TRUE VERTICAL - SENSED BY THE VERTICAL GYRO

Figure 61. Pitch and Roll Angle Error Definition

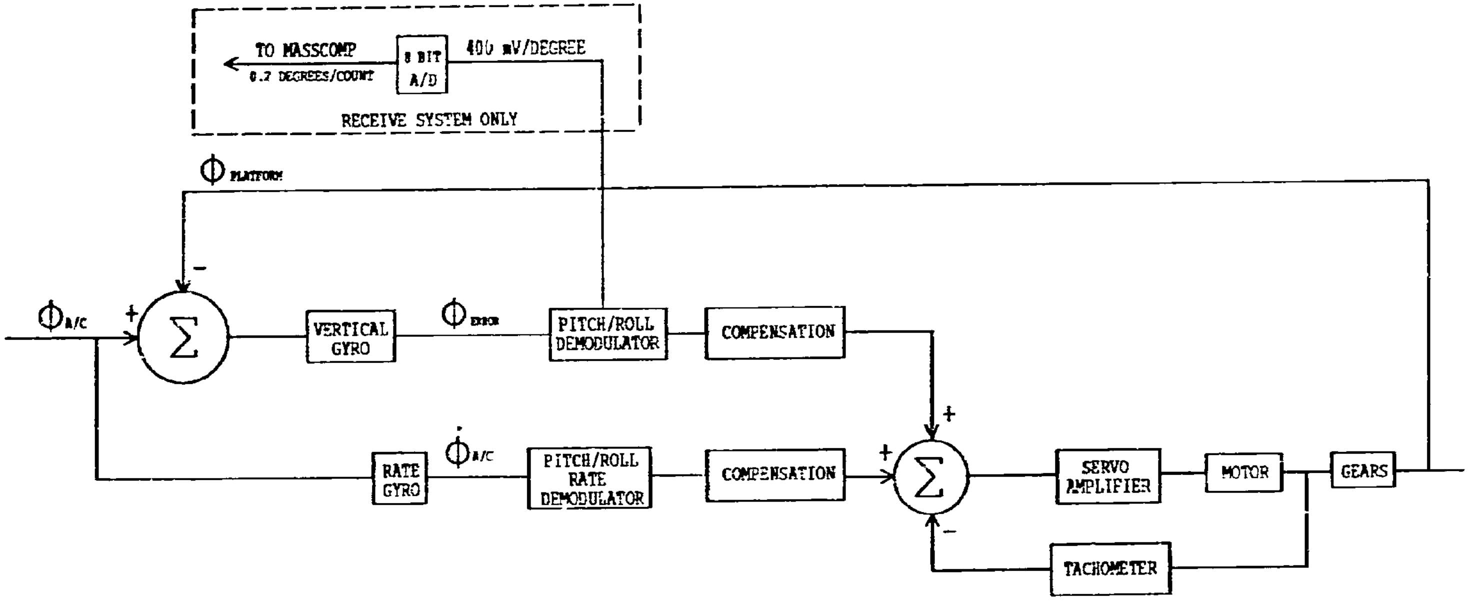


Figure 62. Pitch (or Roll) Servo Loop

The pitch and roll demodulators of the receive system provide an analog voltage output to record in real time the pitch and roll errors. This output, scaled at 400 mV per degree, is put through an 8 bit A/D converter. The A/D has a +/- 10 volt full scale so that the output represents 78 mV per count. This allows recording of actual pitch and roll angle errors to 0.2 degrees. These angle errors are recorded in the Masscomp computer and used in the data reduction to determine actual antenna pointing angles by correcting the elevation and azimuth angles for pitch and roll induced pointing errors.

6.3 ELEVATION

Elevation servos in the two systems are different due to the scanning requirements of the receive system. Figure 63 shows the block diagram of the transmit elevation servo. In this loop the desired elevation angle is input by the operator through the computer keyboard. This command is then converted to an analog voltage that is fed to the antenna controller. The controller compares the desired elevation with the actual elevation as read off the platform potentiometer and generates an elevation rate command to move the platform to the desired position. The motor drives the tachometer to generate a matching rate until the platform reaches the desired position. The elevation position of the platform is also fed back to the computer through an A/D where the antenna elevation angle is displayed on the screen for the operator. Neither the desired nor the actual elevation angle is recorded in the transmit system.

The receive elevation servo as shown in Figure 64 is much more complex. The desired elevation angles are passed from the Masscomp computer to the ACU-6 antenna control unit as a definition of the desired scan sector and desired scan rate. These data are input to the ACU-6 scan pattern generator. The desired scan rate is output from the ACU-6 as a rate command. A synchro

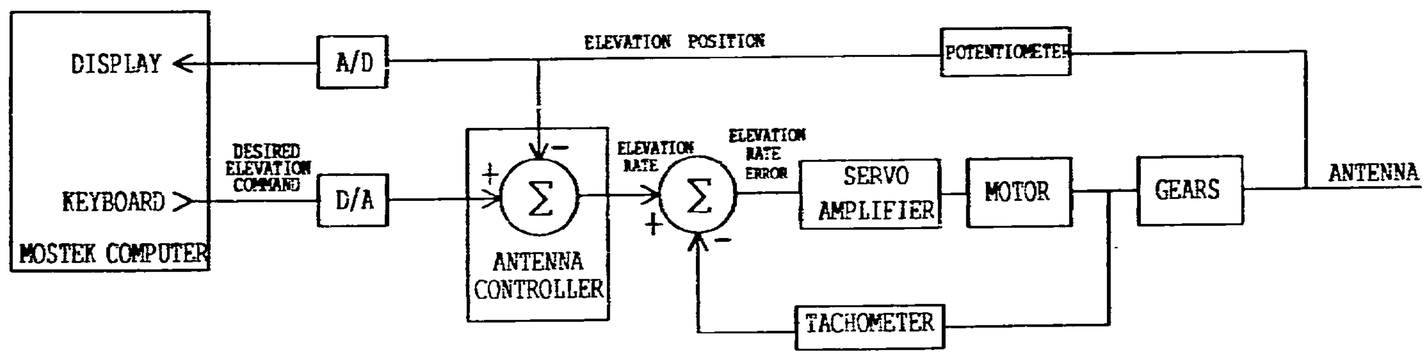


Figure 63. Transmit System Elevation Sevo

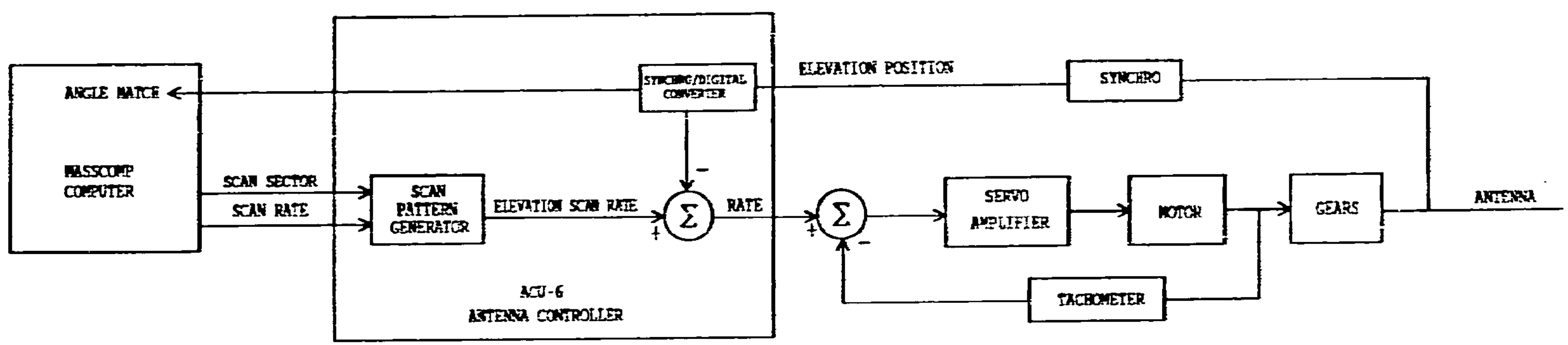


Figure 64. Receive System Elevation Servo

mounted on the platform measures the actual platform elevation position and feeds this back to a synchro-to-digital (S/D) converter in the ACU-6. As the antenna reaches the end of the scan sector the rate command automatically decreases to prohibit excessive overscanning. The S/D converter is also fed back out to the Masscomp computer for recording. The elevation angle is also used to trigger the data collection/data recording process by sending an "angle match" interrupt to the data acquisition control processor (DACP). In a static mode, i.e. when the antenna is pointed at a fixed angle (as in the dynamic data collection scenario), the desired scan sector is passed such that the minimum and maximum elevation angles are the same. In this case the antenna will not be scanned but external loads such as wind loading will be compensated.

6.4 AZIMUTH

Like the elevation servos, the azimuth servos for the transmitter and receiver are somewhat different based on the additional scanning requirement of the receive system. The azimuth has two modes of operation: relative and true. In the relative mode the antenna azimuth is positioned and stabilized 'relative' to the centerline of the aircraft. In this mode aircraft heading is not a factor. This mode is most commonly used during maneuvering of the aircraft into position. In the true mode the antenna is positioned and stabilized with respect to true north heading. In this mode the magnetic heading of the aircraft along with a geographic location dependent compass correction must be accounted for in the positioning and stabilization of the antenna. Figure 65 shows how the antenna azimuth angle with respect to true north is derived.

Figure 66 shows the block diagram of the transmitter azimuth servo. Like the elevation servo, the desired azimuth is provided by the Mostek computer from a keyboard entry by the operator. This entry may be made in either the true or relative mode. In the relative mode the desired azimuth command remains constant until the operator inputs a new position command. The azimuth pointing

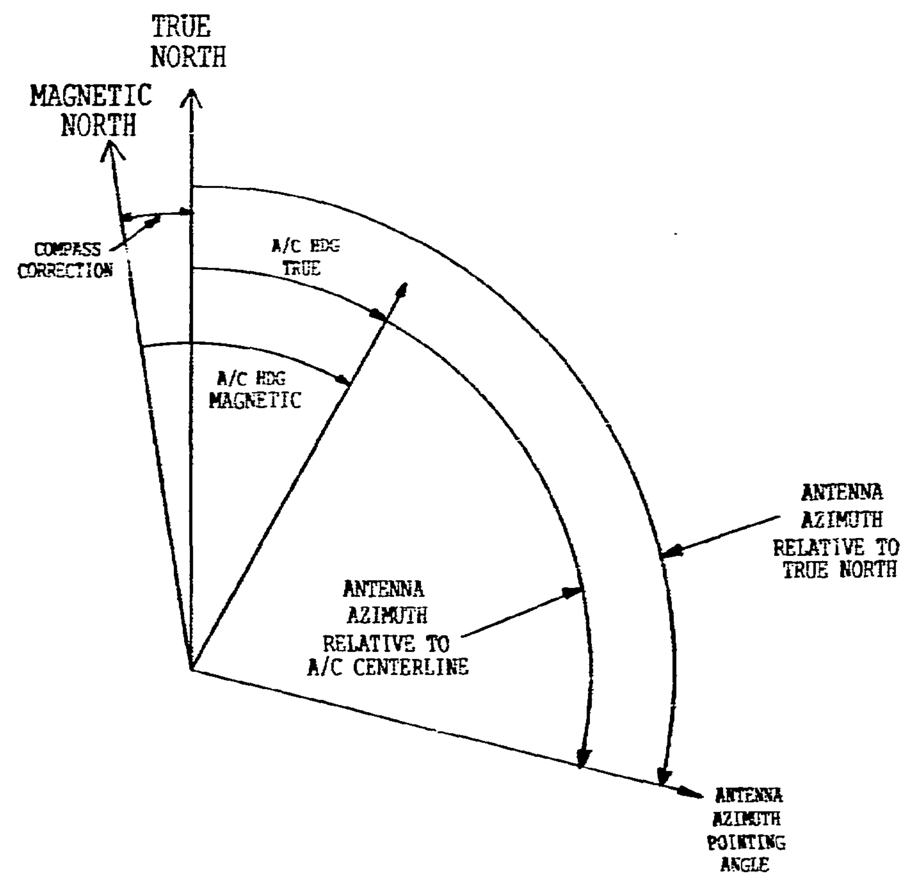


Figure 65. Derived Antenna Azimuth Pointing Angle Referenced to True North

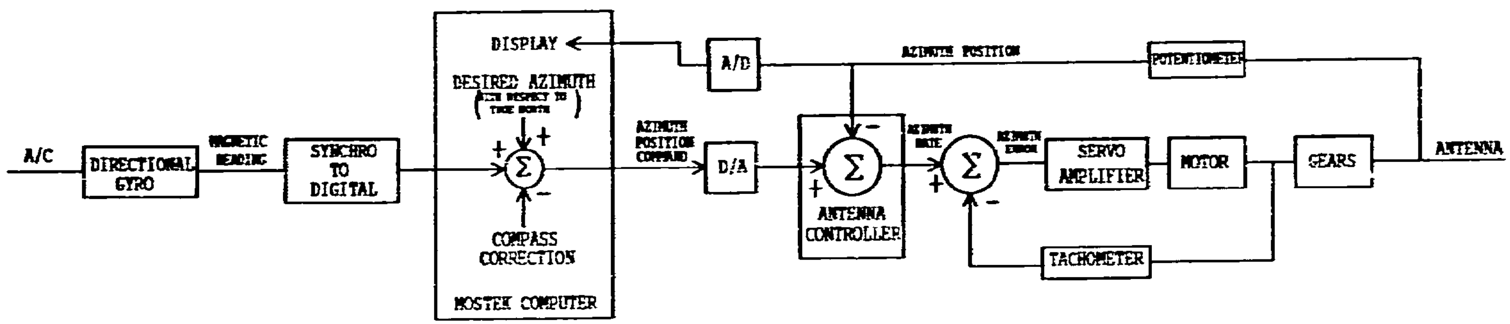


Figure 66. Transmit System Azimuth Servo

angle is maintained using only the azimuth position off of the platform as a feedback signal to the antenna controller. In the true mode the magnetic heading of the aircraft is summed with a magnetic-to-true correction (based on geographical location) along with the desired true heading input by the operator. This provides a constantly changing desired heading command as a function of yaw motion of the aircraft. The antenna controller takes the commanded azimuth position and the actual antenna position and computes uzimuth rate error signal. This error rate is differenced with the tachometer feedback to create a servo error signal. In both modes the azimuth position is read back into the Mostek computer via an A/D converter and displayed on the computer terminal.

Figure 67 shows the block diagram of the receiver azimuth servo. Most of the control is provided by the ACU-6 antenna control unit. The Masscomp computer provides the ACU-6 controller with parameters which include the desired azimuth scan sector to be covered and the azimuth step size. The scan pattern generator then provides the desired azimuth which, in the true mode, is summed with the aircraft true heading to become the azimuth command to the servo.

The receiver azimuth servo is unique to the others in the double shafted drive motor and dual platform position feedback loops. The original design of the servo had the sychro on the power gears driving the platform position as the feedback to the servo loop. In order to maintain the desired accuracy in the azimuth position the servo's forward gain had to be raised in order to keep up with the dynamic yaw inputs in real time flight conditions. Backlash in the power gears however caused the system to oscillate with the higher gain settings. To accommodate this needed gain, the original drive motor was replaced with a double shafted motor. One shaft drives the power gears which move the platform at a gear ratio of 720:1. The second shaft drives a set of precision gears with no backlash. This second set of gears has a ratio of only 180:1. To match the two, a 4:1 timing pulley was added which brought the

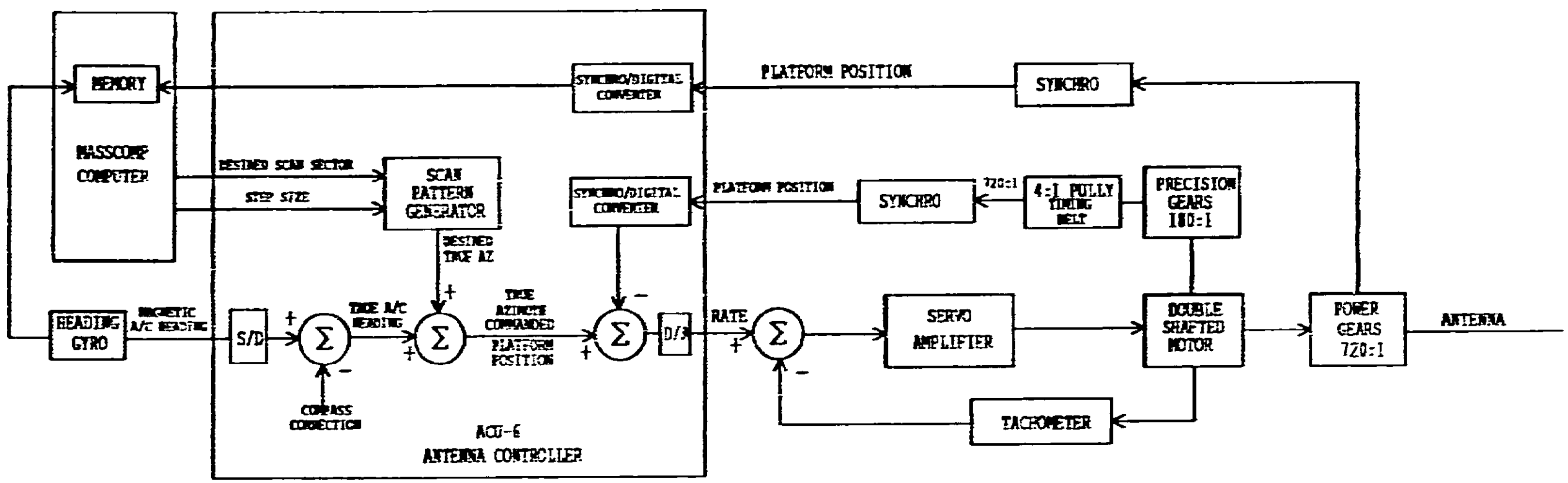


Figure 67. Receive System Azimuth Servo

feedback loop to the same 720:1 ratio. This now provides a very tight control loop. The actual platform position may still be in error from the position measured off of the motor output due to the backlash in the power gears. For this reason the original feedback was maintained as the position feedback that is recorded by the computer and is used in the data reduction.

6.5 PERFORMANCE

Both the transmit and receive systems have electrical and mechanical limits built in to inhibit the antenna motion. The electrical limits are set to contain the total pointing angles in azimuth and elevation to within the area that will not be masked by obtrusions into the field of view by parts of the airframe. The mechanical limits are provided to protect the equipment from damage due to dynamic aircraft maneuvering activities.

The accuracy for which the real antenna pointing angles are known is directly related to the accuracy of each angle measurement in the system. Although the transmit and receive systems are basically identical in their angle accuracy, only the receive angles are recorded in real time. The transmit beamwidth being so large (approximately 30 degrees in both elevation and azimuth) compared to possible angular errors which may total to be 1 degree did not warrant the more complex data recording system to include these angle measurements. Table 6 lists the overall system accuracy for the various axes of motion and the major error sources which are described below.

Pitch and roll errors both become factors in the azimuth and elevation actual pointing angles although pitch motion is more a polarization axis factor and roll error has the most affect on the elevation angle. In the receive system each of these error contributors is measured at the stabilization system and recorded by the computer for future angle corrections in the data reduction. The pitch and roll error angles are read from the demodulators which provide an output at 400 millivolts per degree. This analog error signal is then converted using an 8-bit A/D whose LSB value represents 0.2 degrees. The overall accuracy of the pitch and roll error, however, is predicated on the accuracy of the vertical gyro which measures the angle off vertical. This gyro (Kearfott Model 9000C) is rated to +/- 0.5 degrees verticality.

The elevation angle is measured using a synchro resolver which reads angular changes. The synchro output is converted to digital signals which are used as a digital feedback to the stabilization loop as well as being recorded by the computer. The accuracy of the elevation angle is dependent on two factors: the initial zeroing and the resolution of the synchro-to-digital output. Initial zeroing of the synchro is done as part of a calibration procedure where the antenna is manually set to 0 degrees elevation as measured with a precision inclinometer on the front face of the antenna. The synchro is then adjusted until the digital output reads 0 degrees. The S/D resolution is 6 minutes of arc (or 0.1 degree).

The azimuth angle, like the elevation angle, is also measured using a sychro resolver and synchro-to-digital converter. The initial zeroing of the synchro output is also performed manually by positioning the antenna orthogonal to the aircraft centerline and adjusting the sychro until the output reads 0 degrees. The S/D for the azimuth has the same 6 minutes of arc resolution. In a data collection scenario, however, the heading gyro comes into play in the overall accuracy. The S/D will measure to 0.1 degree the antenna azimuth with respect to the airframe centerline. But the accuracy of the heading gyro will determine the overall accuracy of the azimuth angle measurement with respect to true north. This gyro is only calibrated to +/- 1 degree. Hence this is the largest angle uncertainty contributor.

Table 6 ANTENNA POINTING ANGLE ACCURACIES

Axis	Basic(1) Accuracy	Major Error Source	Relative(2) Accuracy	Absolute(3) Accuracy	Absolute(4) Repeatability
Pitch	±0.5°	Gyro Precision	±0.8°	±1°	±0.5°
Roll	±0.5°	Gyro Precision	±0.8°	±1°	±0.5°
Yaw	±1.0°	Flux Gate Correction Error	±1.0°	±1.0°	±1.2°
Azimuth	±0.1°	Gear Backlash	±0.3°	±1.4°(5)	±0.2°
Elevation	±0.1°	Gear Backlash in Pitch & Roll	±0.4°	±1.4°(6)	±0.9°

(1) Basic Accuracy is the stated accuracy of the instrument which is used to measure the error. For pitch and roll - the instrument is the vertical gyro, for yaw - the directional gyro, and for azimuth and elevation - the synchro.

(2) Relative Accuracy is the precision to which the angle relative to the aircraft reference planes can be determined (includes installation and calibration errors).

(3) Absolute accuracy is the accuracy with which angles relative to a gravity or True North reference can be determined (includes installation, calibration, and A/D quantization errors).

(4) Absolute Repeatability is a worst case estimate of the variable components of the error. Given that calibration and installation errors are constant it is the ability of the system to point the antenna to the same angles.

(5) Absolute accuracy relative to a True North reference and includes installation, calibration, and platform yaw errors.

(6) Absolute accuracy relative to a gravity reference and includes installation, calibration, and platform roll errors.

The above absolute accuracies represent a worst case scenario in which all error contributors add. For an error analysis an rms value should be computed.

Section 7
MICROWAVE LANDING SYSTEM (MLS)

The Microwave Landing System (MLS) provides two major functions in the data collection and data reduction processes. First, in order to collect data at specific geometries a repeated number of times, the MLS provides the position information in real time that is used to guide the pilots in each aircraft to specific positions over the terrain. Secondly, during the data collection process, the actual real-time position data of both aircraft are recorded and later used to define the overall geometry angles that will be associated with the bistatic clutter data.

7.1 STATION KEEPING

During data collection sessions each aircraft receives position information in the form of azimuth, elevation, and range from the ground station. Transmissions from the ground units are decoded by the receiver in each aircraft and provide inputs to an onboard computer running a real time guidance program. This program compares the decoded actual x, y and z position with a preloaded desired x, y, and z position and produces error signals based on the differences which are provided to the pilots displays as a means of station keeping.

7.2 GEOMETRY DEFINITION

In the receive aircraft, the decoded actual position information described above is recorded in real time in conjuction with the radar and other data (including antenna position). On command the transmit aircraft reports its decoded position information via the data link which is then recorded in the receive aircraft. During the data reduction process this actual position information is used to define the geometry in which the radar data were recorded.

7.3 EQUIPMENT DESCRIPTION

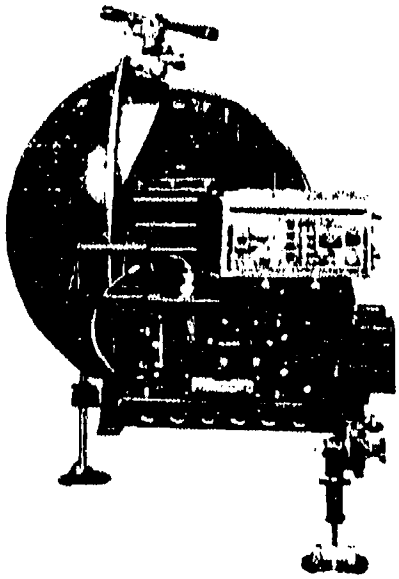
The MLS equipment, built by Eaton/AIL, is provided as GFE for the Terrain Measurements Program. The ground station, the AN/TRQ-33, consists of a localizer unit, a glideslope unit, and a distance measurement equipment (DME) unit. This station provides azimuth angle from the localizer centerline, glideslope elevation angle, and slant range from the DME. Angle information is provided by encoding the angular coverage both in azimuth and elevation through pulse pair positioning. Range is provided by simple time of arrival after a range interrogation. Figures 68a and 68b show the ground station equipment.

Each aircraft is equipped with an AN/ARQ-31 airborne group which receives and decodes the localizer, glideslope, and DME transmissions from the AN/TRQ-33 ground station. Figure 68c shows the airborne set. The decoded outputs from the receiver are normally used to drive indicators for aircraft landing approach. These signals are intercepted and fed to an onboard computer used for station keeping.

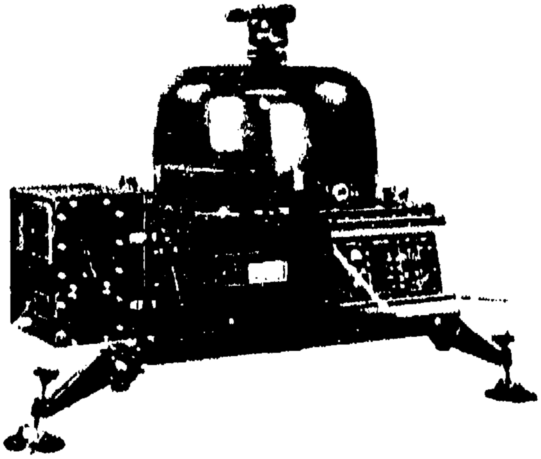
7.4 SCENARIO DESCRIPTION

The MLS is used in both static and dynamic data collection scenarios. In order for the data reduction process to take into account terrain slope the actual positions of the aircraft relative to a terrain map must be known. This means the MLS location in latitude and longitude must be known as well as the MLS magnetic heading (localizer centerline). A surveyed point, e.g. a bench mark, is used at each data collection site to determine the location of the MLS in map coordinates. Since the helicopter positions are known in MLS coordinates they are therefore known in map coordinates.

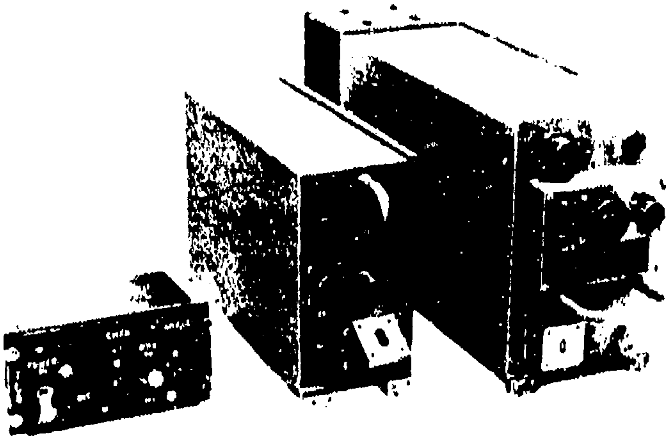
For the static scenario, the ground station is set up at a particular magnetic heading (using a transit compass for alignment) in a direction equal to the wind direction. The two hovering



a) GLIDESLOPE UNIT



b) LOCALIZER UNIT



c) AIRBORNE GROUP

Figure 68. MLS Equipment

helicopters are positioned downwind some distance from the ground station headed into the wind. Heading into the wind provides the best means of controlling the aircraft for the pilots. The typical scenario has the aircraft positioned symmetrically about the localizer centerline as shown in Figure 69, although this symmetry is not a requirement. Azimuth angle, elevation angle, and range information that is received by the airborne set is decoded and passed to an onboard computer. In this computer the information is transformed to an x, y, z coordinate system with the MLS ground station at the origin. This actual x, y, z position is compared to a preloaded desired x, y, z position and errors in all three axes computed. These errors are then transformed to a new coordinate system with the aircraft at the origin in order to drive the pilot's indicators to show position correction requirements as 'fly-to' directions.

During the dynamic scenario, the receive helicopter hovers on the localizer centerline at a distance of about 8 miles from the MLS and at a heading 270 degrees from the centerline. In keeping with the desire to head the aircraft into the wind, this means the MLS centerline is oriented 270 degrees from the direction of the wind. The transmit aircraft flies a race course which takes it over the MLS ground position and follows the localizer centerline out in the direction of the hovering receive aircraft. This scenario is shown in Figure 70.

7.5 PERFORMANCE

The MLS system is primarily intended to be used as a guidance system for landing approaches. The elevation coverage of the glideslope unit encodes space from 0 to 20 degrees. However, for best accuracy the elevation coverage should allow for one beamwidth scanning either side of the desired glideslope angle. This, along with multipath at the lower angles and beam distortion due to the radome at the upper angles limits the usable range of elevation angles for this application to about +4 to +14 degrees.

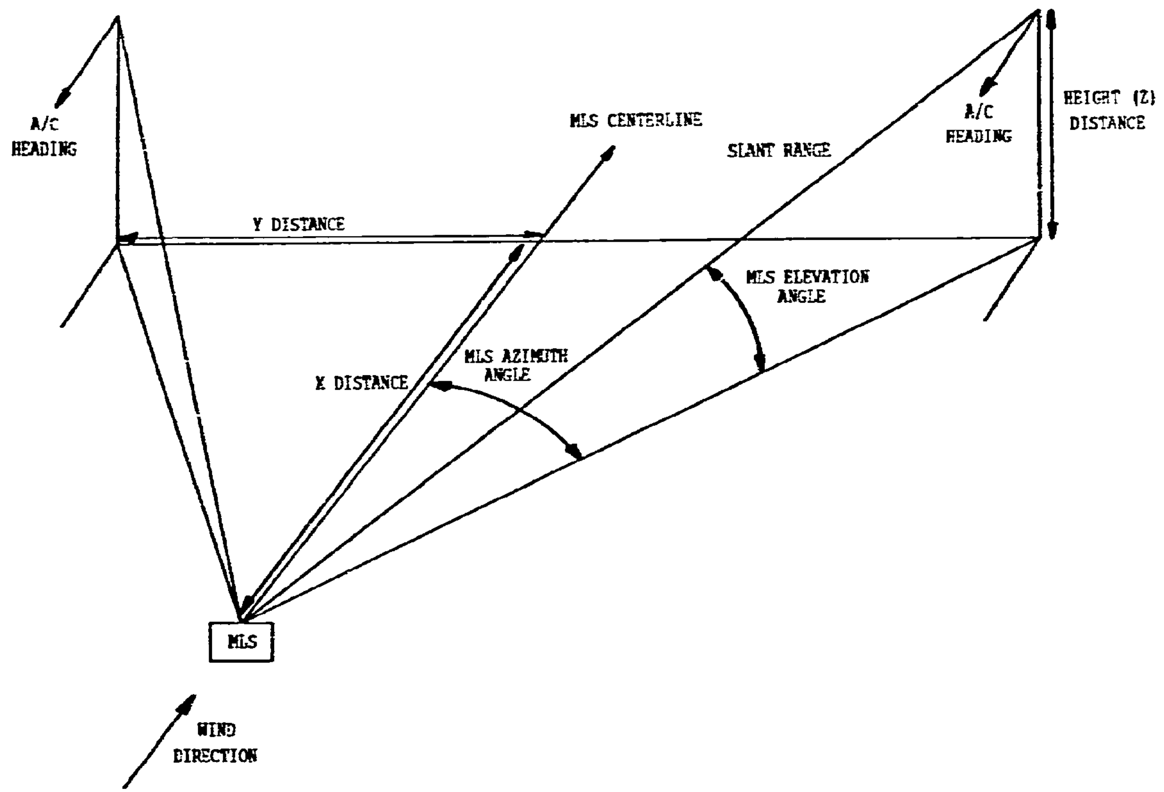


Figure 69. Aircraft Positioning - Static Geometry Scenario

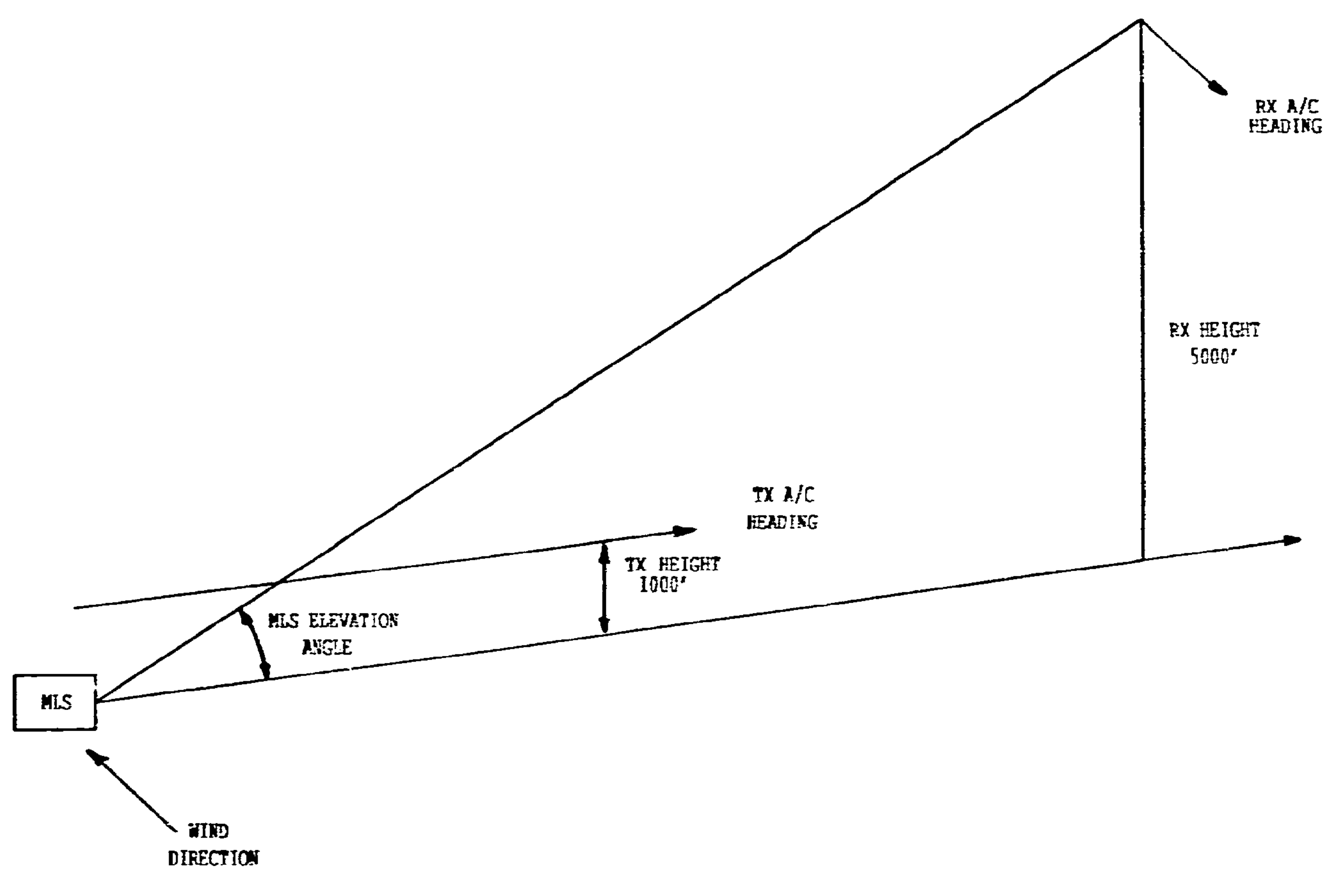


Figure 70. Aircraft Positioning - Dynamic Geometry Scenario

The azimuth coverage of the standard localizer unit is +/- 30 degrees from centerline. The localizer unit used on the Terrain Measurements Program was modified by Eaton/AIL to cover +/- 60 degrees. Like the glideslope unit, however, allowing for one beamwidth scanning beyond the desired angle and radome distortion of the beam decreases the usable angles to about +/- 55 degrees.

The angle accuracy of the localizer and glideslope units is reported by AIL to be +/- 0.1 degree on axis. Since most of our scenarios position the aircraft purposefully off axis (for the glideslope unit in particular), the reported accuracy may not apply. For this reason the glideslope unit had to be calibrated in the region of use, mainly off the centerline where beam distortion is most prevalent. A beam shape calibration was performed by a Calspan/AIL team during the first site visit at WSMR using a Boresight Measurement Unit (BMU) located on the range. Using data from these measurements, AIL developed a calibration curve and correction equation that was later used in the data reduction programs to correct the recorded MLS data. Figure 71 shows the correction curve used. Note that prior to the calibration an offset existed in the glideslope unit. The unit was adjusted on site and a new set of calibration data taken. Hence, the double curve. During the WSMR BMU calibration procedure, the localizer unit was also rechecked for its modified azimuth coverage. It proved to be still within its accuracy limits so that no localizer calibration curve is required.

At the initial start up at each site thereafter the MLS calibration was rechecked. This was done by statically positioning one of the aircraft at specific locations within the MLS coverage beam and simultaneously recording the MLS receiver digital output data with independent sightings of aircraft position using a co-located transit at the MLS ground station position. Multiple data samples at each discrete position were recorded to average out any time lag errors between digital data recorded and ground based manual measurements. These manual checks of the calibration curve

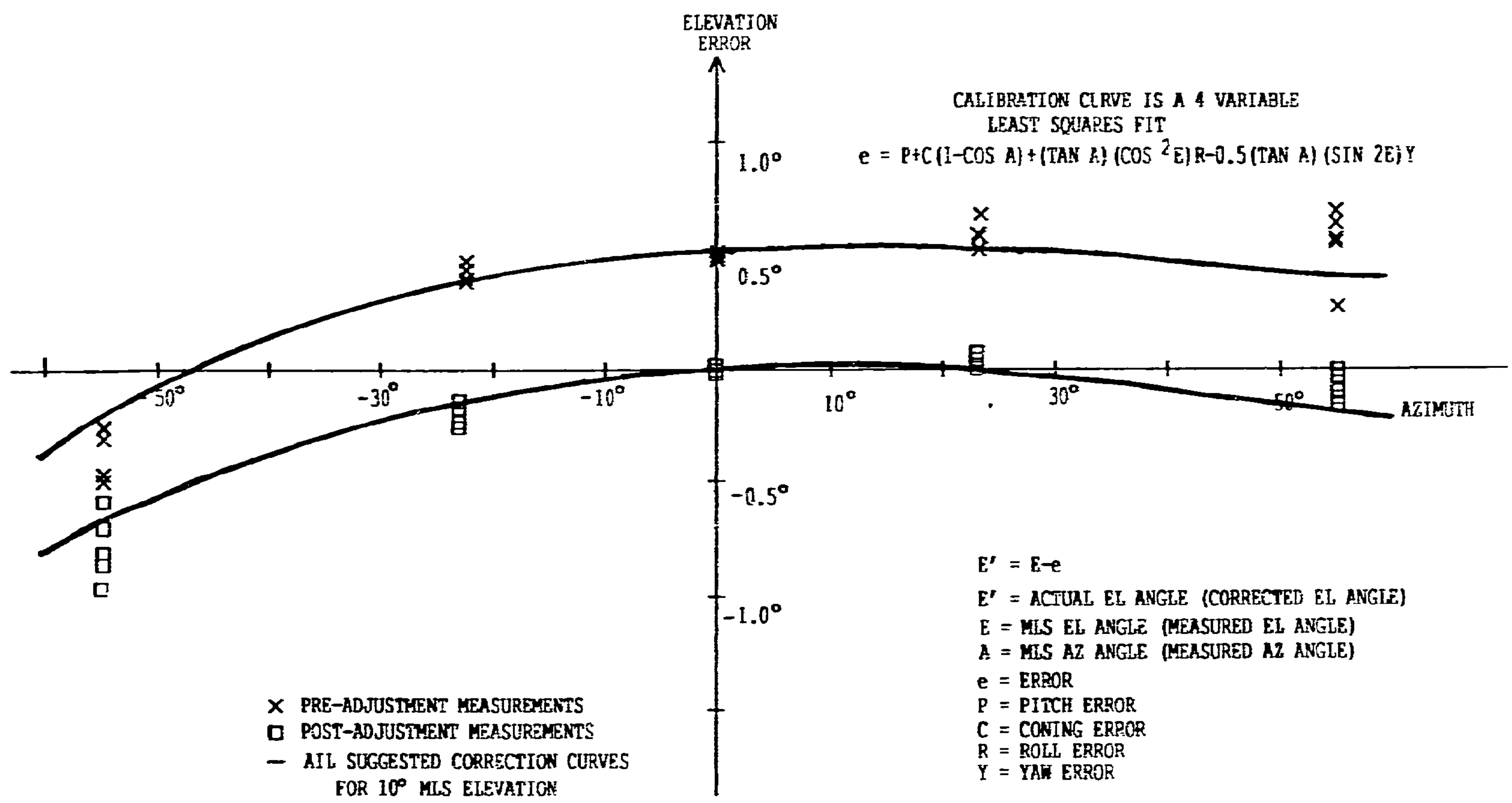
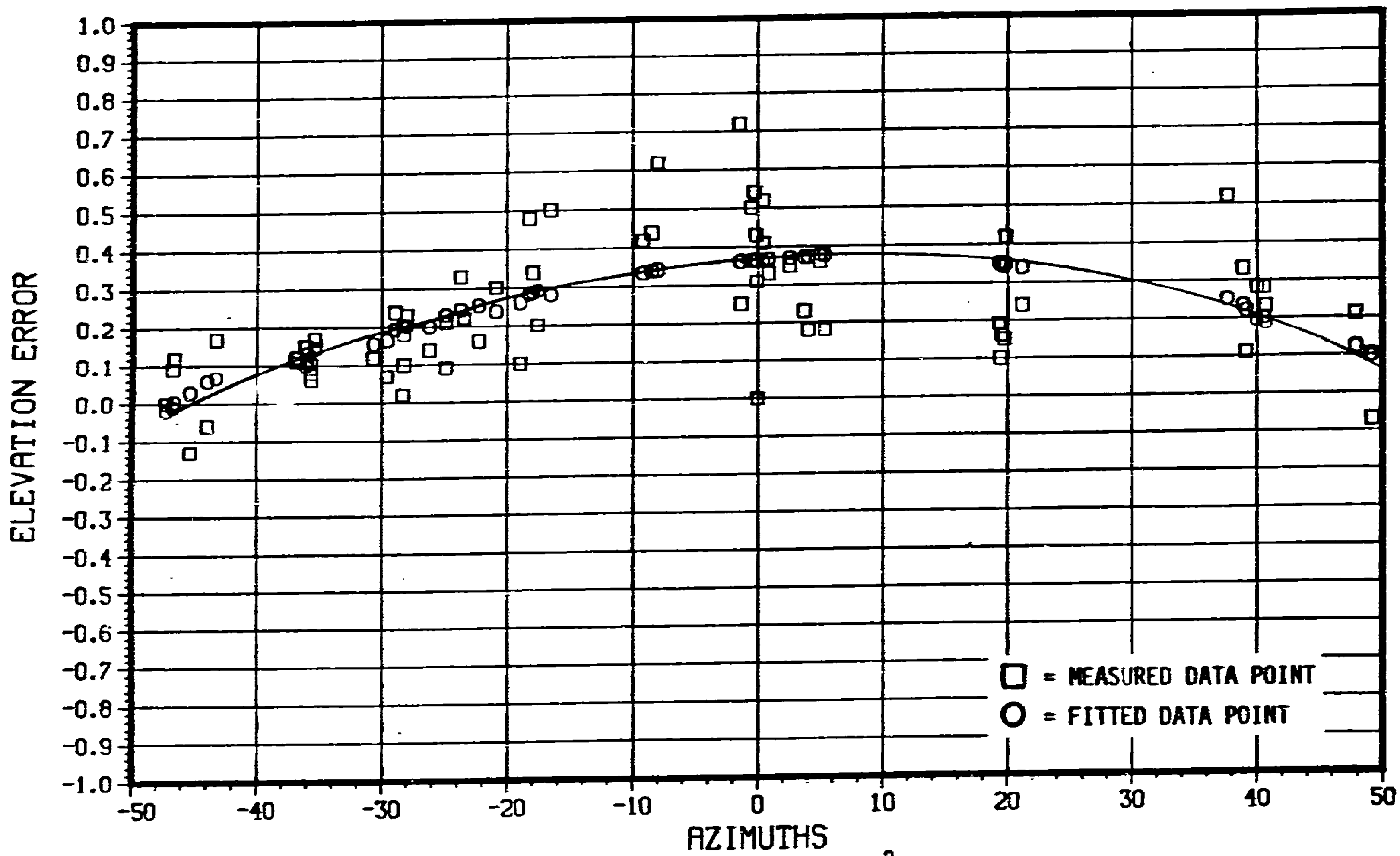


Figure 71. MLS Glideslope Calibration Curve (Sites 1 Through 4)

showed consistency of the position correction to about 0.1 degree error. A failure in the magnetron of the calibrated glideslope unit required replacing the glideslope unit with another uncalibrated unit. Several data gathering flights to collect MLS digitized data versus ground based transit readings were used to develop a calibration curve for the new unit. This curve is shown in Figure 72.

The Distance Measurement Equipment (DME) was calibrated at AIL and included a measured offset in the range reporting to accommodate turnaround delay in the unit. Measurements with a laser range finder used in conjunction with the transit measurements for MLS angle calibration agreed with this range offset to within a few feet.



CORRECTION = -(PCOR-CCOR*(1-COS(AZ))+TAN(AZ)*(RCOR*COS(EL)^2-(YCOR/2)*SIN(EL*2)))

WHERE CCOR = 0.6654
PCOR = 0.3700
RCOR = -0.3949
YCOR = -2.7048

NOTE: ERROR = -CORRECTION

Figure 72. MLS Glideslope Calibration Curve (Site 5)

Section 8

DATA ACQUISITION AND DATA REDUCTION SOFTWARE

The data acquisition software consists of both off-line set-up programs and real-time data collection programs. Each of these will be described in the sections to follow. The data reduction software for field use includes several "quick-look" routines that allow an on-site verification that good data has been collected. Final data reduction software, implemented on the IBM main frame at Calspan, reduces the radar data to the sigma zero output for analysis. An overview of the software is shown in Figure 73.

8.1 Overview

The data collection software consists of pre-flight and real-time software programs. The pre-flight programs include set-up software which calculates, from the desired aircraft positions, the sampling system delay settings based on the time of arrival (TOA) for the desired geometries. Other pre-flight software programs provide means to perform system checks and calibrations. Real-time programs control the experiment from data acquisition activities to setting system parameters. Real-time programs are provided for both static and dynamic data collection scenarios. In addition, real-time position station-keeping software runs independently of the data acquisition providing the guidance information for the pilot's display. This software program interacts with the data acquisition software only when the current aircraft position information is needed for recording by the data acquisition program.

Post-flight data reduction using a "quick-look" software program allows for a fast turnaround look at the data that has been collected. This program can look at each data set individually and print out the raw data in formatted listings which show the data collected from position information, to raw radar return amplitudes, to status information of various system elements. If desired, the quick-look program will even plot out the reconstructed radar video that has been digitized. Processing

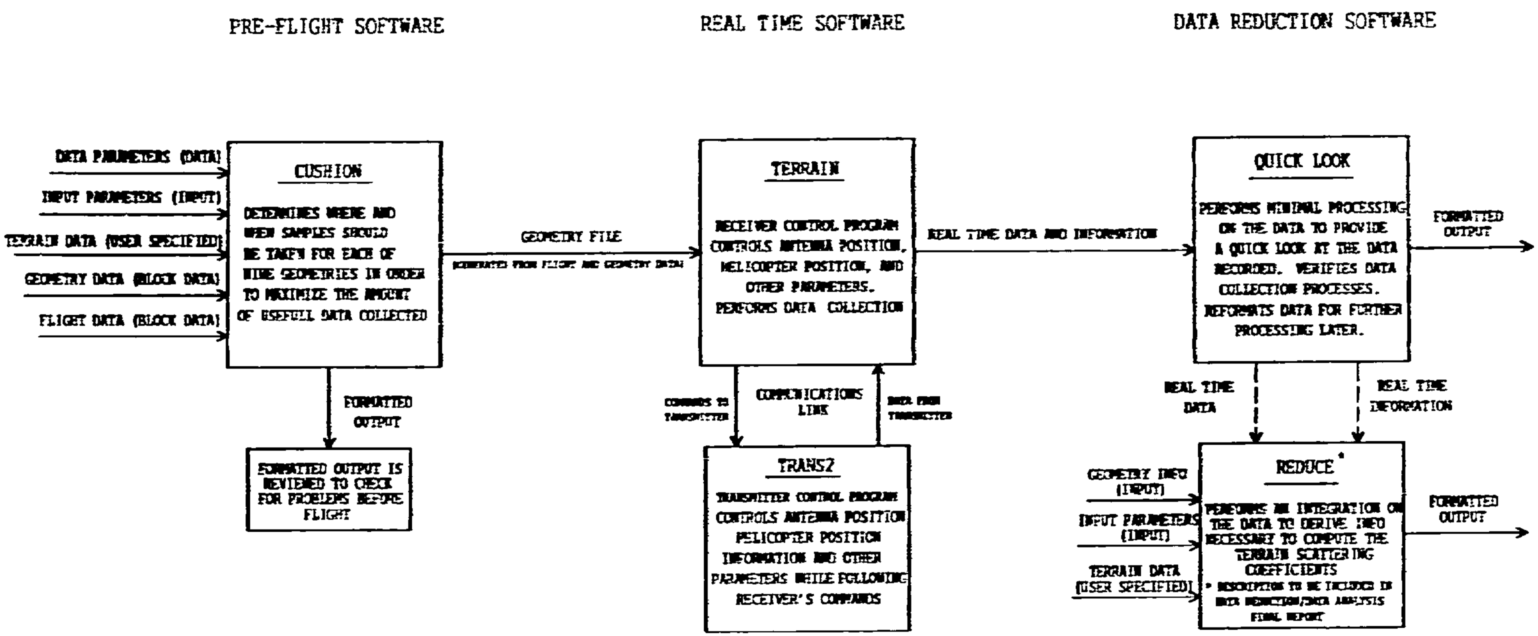


Figure 73. Terrain Measurements Data Acquisition and
and Data Reduction Software Overview

of the data beyond this is left to the full reduction software at Calspan. The following sections discuss each of the software programs mentioned in more detail.

8.2 Pre-Flight Software

8.2.1 Terrain Data Collection Setup

The first step in setting up for a terrain data test is to determine which specular angles are of interest. The relative positions of the transmitter and receiver helicopters are then computed to achieve the desired specular angle. Other considerations factored into the positioning of the helicopters include coverage of the MLS and flight safety guidelines. The MLS baseline is adjusted to position the helicopters in the proper area and to assure coverage by the MLS. Calspan uses a set of five base setups or data sets for terrain tests as detailed in Table 7. (See Figure 3). Each geometry setup may use different antenna scan pattern. The geometry ID indicates the scan pattern used. For example, a geometry ID of "a" may indicate an azimuth sector from 0 to 20 degrees while a geometry ID of "b" indicates an azimuth sector from -10 to 10 degrees.

Table 7

NOMINAL TERRAIN DATA COLLECTION GEOMETRIES

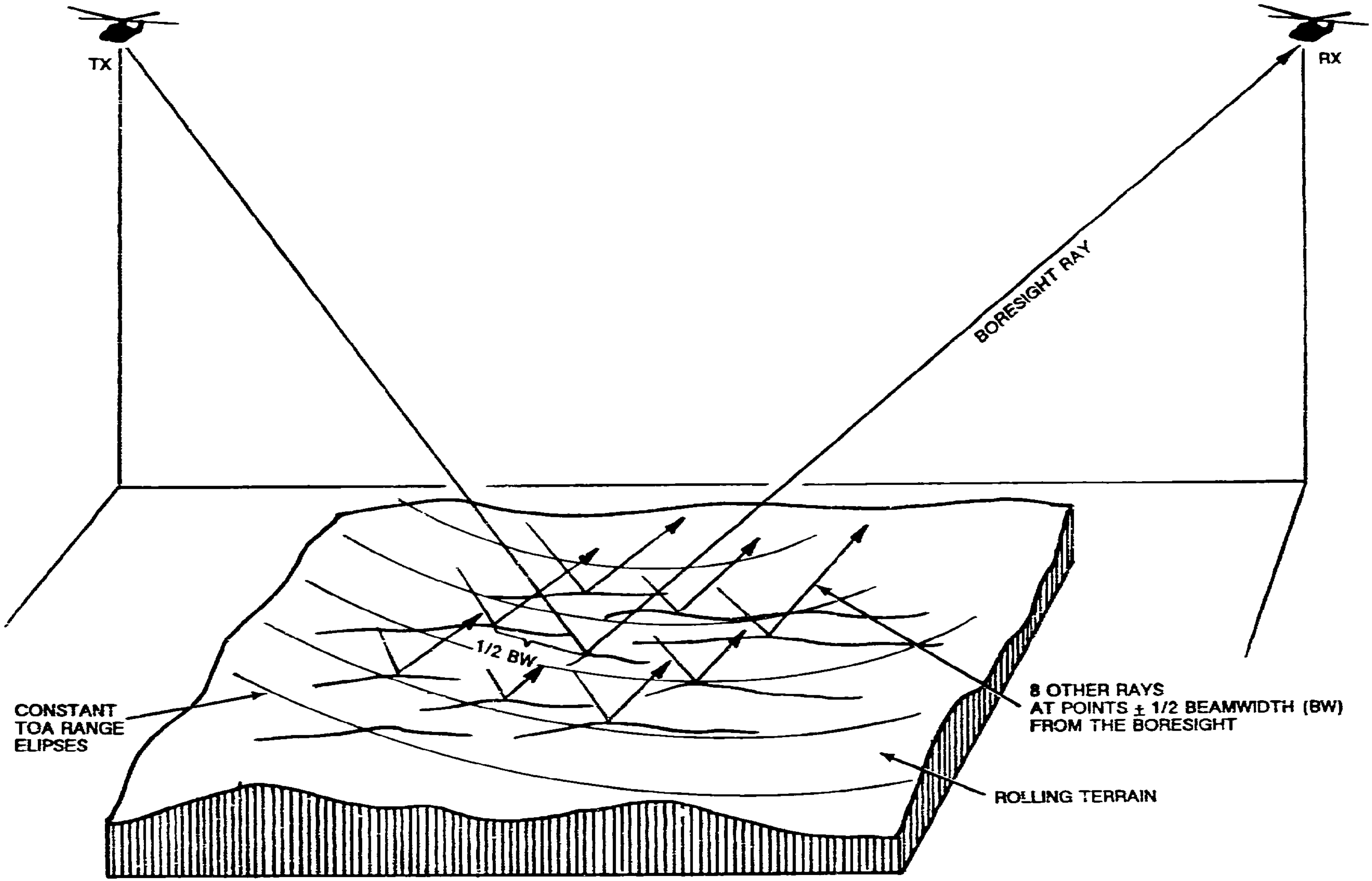
Geometry ID's	Specular Angle	MLS Baseline [1]	XMT & RCV Altitude [2]	XMT & RCV Separation
a, b	6 degrees	7500-15000 feet	1034 feet	19676 feet
c, d	10 degrees	7500-15000 feet	1480 feet	16786 feet
e, f	14 degrees	7500-15000 feet	1590 feet	12754 feet
g, h	20 degrees	7500-15000 feet	1590 feet	8736 feet
i, j	26 degrees	7500-15000 feet	1590 feet	6520 feet

1. The baseline was varied to place the specular on the desired terrain type.

2. The height of the transmitter and receiver above the terrain will vary. The height listed here is the height above specular.

The next step involves computing which times of arrival should be used to sample the data in order to collect the data of interest. The data of interest comes from the footprints of the receive beam on the ground. See Section 2. There is a limitation on the amount of data which can be collected based on data rates, computation speed, disk and memory limitations and practical considerations. In order to meet these limits, the minimum data necessary to assure that the desired information is captured is collected. Given the position of the MLS, the position of the transmitter and receiver and an accurate digital representation of the terrain, it is possible to compute the times of arrival for the desired data. For each azimuth and elevation at which data are to be collected, the extent of the receiver footprint, in time, is estimated. This is accomplished by finding the intersections of the boresight ray and the half beamwidth rays with the ground. The half beamwidth rays are those off the boresight ray by half a beamwidth (in this case, 1 degree) in azimuth, elevation or both. This procedure defines nine points placed at three elevations and three azimuths. The times of arrival from the receiver to the transmitter via these nine points are computed. The estimated footprint is defined by the time from the minimum of these nine times of arrival to the maximum of the nine times of arrival. See Figure 74.

The estimated footprints are found for the nominal position. That is, the times of arrival are valid only if the helicopters are in the desired position (and the digital map is a true representation of the terrain). There will often be some deviation from the desired position during hovering and terrain features such as trees are not accounted for in the DMA digital maps. To accommodate these two sources of time of arrival deviation, a cushion is added to the footprint extent. The cushion is selected to maximize the probability of collecting the desired data with the minimum affect on system resolution. Factors considered in determining the cushion include the roughness of the terrain, the geometry selected and previous real-time data when available. The cushion size currently being used varies from 100 and 400 nanoseconds. The cushion is



MESSAGE: MINIMUM AND MAXIMUM TOA DEFINED BY THE TOAS AT 9 POINTS INCLUDING THE BORESIGHT RAY INTERSECTION AND 8 OTHER RAY INTERSECTIONS AT ANGLES ± 1/2 BEAMWIDTH IN AZIMUTH AND ELEVATION FROM THE BORESIGHT OVER TERRAIN HEIGHT VARIATIONS

Figure 74 MINIMUM AND MAXIMUM TIME OF ARRIVAL (TOA) OF RECEIVE BEAM FOOTPRINT

added to the maximum and subtracted from the minimum time of arrival in the footprint to define the sampling window. See Figure 7.

Once the window is computed, a sampling scheme must be defined. The object is to sample in a way which meets hardware, software and practical limits and still maximizes the chance of collecting the necessary data. Table 8 contains a list of the current limits. The transmitter pulsewidth is fixed between 20 and 60 nanoseconds and the window is sampled at half pulsewidth increments.

Note that the above is the setup for the collection of terrain data. In the reduction of terrain data, leading to σ°'s, actual recorded helicopter positions, antenna pointing angles, etc. are used with terrain heights to compute sampling times, footprints, and footprint areas.

Table 8
DATA COLLECTION LIMITS

Item	Limit	Reason for Limit
Maximum number of delays per azimuth	255	Delay generator
Maximum pulsewidth	60	Clear pulse; no interference with direct
Minimum pulsewidth	20	Uncertainty in a/c location
Maximum samples time delays per gulp	200	Data store

8.2.2 Direct Beam Setup

The direct beam setup is considerably simpler than the terrain setup. The main bang is precisely timed to be transmitted 1800 nanoseconds after the timing pulse. Since the timing pulse (See Section 2) and the main bang travel the same distance, the time of arrival for the main bang at the receiver is 1800 nanoseconds after the timing pulse is received regardless of position or other factors. A pulsewidth of 60 nanoseconds is used and samples are taken from 1700 to 1955 nanoseconds at 1-nanosecond intervals.

8.3 IN-FLIGHT (REAL-TIME) SOFTWARE

The inflight software controls all of the equipment during the test including radar control, antenna control, and data acquisition. A diagram of the systems under in-flight software's control is shown in Figure 75.

8.3.1 Terrain

This large program written mostly in FORTRAN controls and directs the real time data collection of radar data. It also supervises and communicates with software and hardware that actually collect radar data.

The initialization phase of this program begins with prompting the operator for desired changes in flight parameters. Usually these changes include updating the flight ID number and the list of geometry file IDs. Some initialization of time delay arrays for the Berkeley Nucleonics time delay generator is then performed. Communication is started with devices connected to the Data Acquisition Processor and log files are opened as necessary. A small set of radar data is collected to provide calibration.

The program runs continuously in a loop prompting the operator for the next geometry file identification number, until the operator enters a "Stop". Within this geometry loop, there is another initialization that is handled by the subroutine INITGEOM, described in Subsection 8.3.1.3. This subroutine waits until both ships are in position before returning control to the main program. Within this geometry loop, there is an azimuth step loop. Radar data are collected for several (about 10) different azimuths evenly spaced, as determined by the input geometry file. At each azimuth, data are collected for different polarizations (usually three polarizations: horizontal, right circular, and vertical). For each azimuth and polarization pair, data are collected for a number of different antenna elevations angles. See Figure 11. At the beginning of each azimuth polarization pair, three arrays of parameters are passed to the separate and independent Data Acquisition Processor

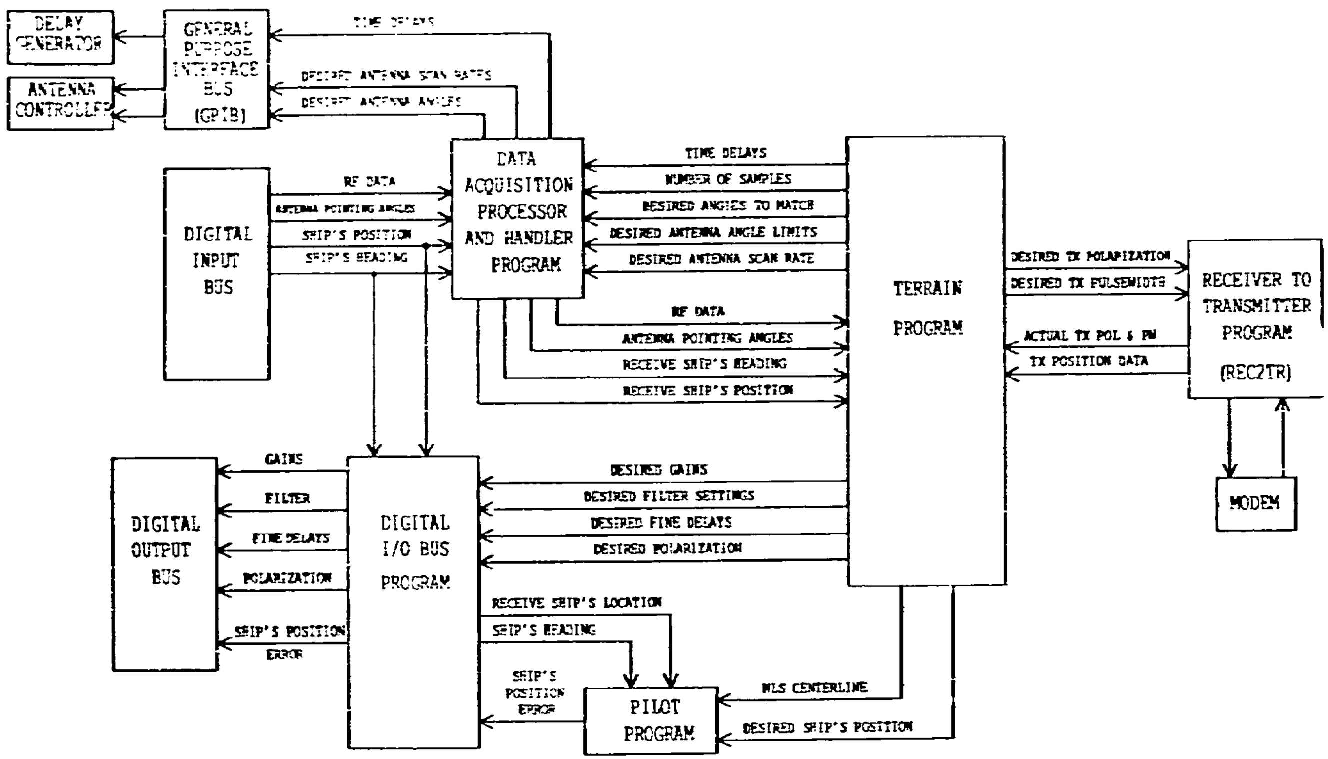


Figure 75. Terrain Measurements In-Flight Software Control

(DACP), and this processor starts to collect data as the antenna sweeps past the desired elevation angles. When the DACP finishes collecting data for each particular elevation angle, it sends an interrupt to the TERRAIN program, notifying TERRAIN that it may process the buffer it has just filled, while the DACP goes on to collect data at the next elevation angle. TERRAIN calls a buffer completion routine, which packs this latest buffer data (varies in size depending on the angle) into a larger fixed size buffer along with the transmitter ship's position data. When all the data for all the elevation angles at the current polarization azimuth pair is collected, TERRAIN calls a routine FINISCAN which will write a full large buffer to a permanent disk file. After all data for all polarizations and all azimuths have been collected, the last buffer is written to the disk file and the disk file is copied onto a 9-track tape, providing two copies of the data collected. A second short data collection is done for calibration purposes.

8.3.1.1 Inputs. The terrain program inputs come from three main sources. These are (1) a disk file (called a geometry file created by the pre-flight program), (2) the test operator during initialization phase, and (3) the hardware devices reporting conditions during real time data collection.

The geometry file contains:

1. Desired location of both ships relative to the MLS
2. Pointing angles of the receiver antenna and the transmit antenna
3. The number of samples to '.e collected at each antenna azimuth, elevation pair
4. The high speed sampler time delays for each antenna, elevation pair
5. The transmit radar pulsewidth

The test operator may set or change the following parameters:

1. The flight identification number

2. The list of geometry file IDs, which determine the files actually used for the flight (they depend on both site and wind direction)
3. The MLS centerline angle relative to true north in degrees
4. The compass correction factor in hundredths of degrees (depends on site location relative to true north)
5. The number and sequence of antenna polarizations to be used
6. The mapping of the high speed radar sampler hardware channels to the logical channels
7. The radar receiver gains

The real time readout of devices includes:

1. The MLS azimuth, elevation and range of both ships (receiver and transmitter)

2. The receive antenna pointing angles (azimuth, and elevation)

3. The aircraft magnetic heading

8.3.1.2 Outputs. TERRAIN output consists of real time data saved for analysis and control data used during flight. The real time data stored for analysis is divided into high speed data and low speed data. High speed data is collected each PRI. Low speed data are collected once per elevation angle.

High speed data consists of:

1. Sampled radar data
2. Antenna pointing angles (az, el, pitch, roll)

Low speed data consists of:

1. Radar parameters
2. Ship's position data (both receiver and transmitter)
3. Aircraft magnetic heading

Control data during the flight consists of:

1. Desired ship's position to PILOT program
2. Current Microwave Landing System centerline (relative to north) to PILOT program
3. Desired transmit pulse width to REC2TR program
4. Desired transmit polarization to REC2TR program
5. Time delays to delay generator (BERKELEY NUCLEONICS 7085)
6. Desired antenna pointing angles and scan rate to the Antenna Control Unit (ACU6)
7. Filter settings
8. Fine delay settings to the samplers
9. Receiver gains
10. Receiver polarization
11. To DACP - number of high speed sampler channels
12. To DACP - number of low speed channels
13. To DACP - number of elevation match angles
14. To DACP - an array of the data channels from which the data is to be collected (both high and low speed)
15. To DACP - an array of elevation angles to match with
16. To DACP - an array of the number of samples to collect at each elevation angle
17. To DACP - an array of commands to be sent to the time delay generator

8.3.1.3 Major Subroutines. Major subroutines of the real-time terrain program include the following.

INITGEOM

This reads a geometry parameter file, sets up the center and size of the antenna scan, opens output data disk files, sets up possible antenna gains. checks ship's position and waits for approximate position and the desired heading to be achieved before starting the antenna scan and data collection.

READX

This routine collects scans of "dummy data" until the antenna moves to the real first azimuth.

INITSTEP

This initializes the pulse width, bandwidth, delays and sets up arrays for loading the delay generator.

INITSCAN

This sets up the hardware antenna gains for the current polarization, loads the receiver delay generator, sends appropriate parameter arrays to the data acquisition processor, and sends corrections for ship's position to the guidance program.

MRXING

This starts the data acquisition processor for the current scan.

SETPOLAR

This sets the receiver polarization for the next scan.

SENDPOL

This sends the desired polarization to the transmitter ship via the data link.

FINISCAN

This reads the MLS data, calculates ship's position, and writes scan's data to the disk file.

FINIGEOM

This sets up receiver location for PILOT and writes final buffer of data to the disk file.

8.3.2 REC2TR

This program processes all communication from receiver ship software to transmitter ship software and visa-versa, via a telecommunications link. This program maps an array to a physical address in reserved memory on the host computer, the MASSCOMP. The Terrain program also maps to this address in physical memory (not virtual memory) allowing the two programs to communicate while running independently. REC2TR then loops, checking a flag in the reserved memory. If the flag indicates that the TERRAIN program has a new command to send to the transmitter ship, this program handles sending the message to the transmit ship. The command or message has been previously stored in reserved memory by the TERRAIN program. This program REC2TR also reads messages from the transmit ship, if the command to read has been previously issued.

8.3.2.1. Inputs to REC2TR from the main TERRAIN program include:

1. TERRAIN request to send desired polarization state to transmitter
2. TERRAIN request to send desired pulsewidth to transmitter
3. TERRAIN request to read transmit ship position

8.3.2.2 Outputs. Outputs from REC2TR include:

1. messages to the transmit ship for all the above inputs

2. transmit ship position to the TERRAIN program

8.3.3 PILOT

Given a desired location for the receiver ship, this process calculates the different between the actual ship's position and desired position at regular time intervals. It also sends the commands necessary to update the pilot's station keeping display. The TERRAIN program and PILOT communicate while running independently. PILOT continuously runs on an auxiliary computer. TERRAIN passes to PILOT the desired aircraft coordinates at the start of each data set.

8.3.3.1 Inputs. Inputs to PILOT include:

1. desired receiver ship position relative to the Microwave Landing System (MLS) in x, y, and z coordinates.

2. Microwave Landing System centerline relative to true North.

3. actual receiver ship position relative to Microwave Landing System from the MLS receiver.

8.3.3.2 Outputs. Outputs from PILOT include the commands necessary to update the pilot's station keeping display.

8.3.4 DIOB

This program handles all requests from real-time software to devices on the digital bus. It prevents PILOT and TERRAIN programs from attempting to write to or read from the digital bus at the same time. Both programs have an area of reserved memory for storing requests to the digital I/O bus. The DIOB program checks these message areas alternately as long as the real-time programs are running.

8.3.4.1 Inputs. Inputs to DIOB include:

1. type of message (read or write)
2. the number of channels to read or write
3. the address of the message data to read or write.

8.3.4.2 Outputs. Outputs from DIOB include:

1. data on the devices on the digital bus
2. data to TERRAIN from devices on digital bus
3. data to PILOT from devices on digital bus.

8.3.5 DACP

The Data Acquisition Processor handler program has the function of recording high speed radar data in buffers which are then sent to the TERRAIN program. This handler is initialized by the TERRAIN program with several arrays of data for every elevation scan of the antenna. After this initialization, the data collection is driven by interrupts from the timing signal that originates on the transmit ship. After the interrupt, the handler reads the first digital channel from the list of channels. The data from the first channel is compared with one of the parameters from the TERRAIN program. The numbers being compared are usually antenna elevation angles, but they may be other numbers as simple as counters. If the numbers do not match, the DACP handler waits for the next timing interrupt and continues to read the first channel and compare until they do match. When a match is found, the program changes the state of the program by setting a flag, and proceeds to collect one full set of channels. This data is stored in a buffer in main memory. The handler then gives up control and waits for the next timing pulse interrupt. When the next interrupt is received, the handler does not try to match angles, but immediately collects another full set of channels. This continues until all the data for all samples, for all range cells are collected. Then the handler changes the state of the program back to reading the first channel and matching numbers. This continues until all the data for all the elevation angles ("gulps") are collected. After every elevation angle or "gulp", the DACP handler sends an interrupt to the TERRAIN program indicating that one of the requested buffers has been filled. The TERRAIN program can then process one buffer while the DACP handler goes on to fill another buffer at the same time (in parallel).

8.3.5.1 Inputs. The DACP input consists of control parameters sent from the master in-flight program TERRAIN, and real-time data collected from devices communicating with the Data Acquisition Processor (DACP).

Parameters from TERRAIN include the following:

1. The number of high speed sampler channels
2. The number of low speed channels
3. The number of elevation match angles (or "gulps" of data to collect)
4. An array of the data channels from which the data is to be collected (both high and low speed)
5. An array of elevation angles (or any numbers that the handler must match to one of the input channels to start data collection following an interrupt)
6. An array of number of samples to collect at each elevation angle (or "gulp")
7. An array of commands to be sent to the time delay generator (one for each "gulp").

The DACP input from the real-time devices consist of:

1. The high speed sampled radar data
2. The antenna azimuth and elevation angles
3. The Microwave Landing System (MLS) data consisting of ship's azimuth, ship's elevation and ship's range
4. The antenna polarization
5. The video filter settings
6. The receiver gains.

8.3.5.2 Outputs. The DACP output consists of data sent to the TERRAIN program for recording on disk and control data sent to devices. Data which is sent to TERRAIN for recording consists of:

1. The high-speed sampled radar data
2. The antenna azimuth and elevation angles
3. The Microwave Landing System (MLS) data consisting of ship's azimuth, ship's elevation and ship's range
4. The antenna polarization
5. The video filter settings
6. The sampled receiver gains.

Control data consists of the ship's position error data sent to the pilot's station keeping display.

8.4 Post-Flight Software

Post-flight software provides for handling of the recorded data off-line to make back-ups, copies, and some quick in-the-field processing.

8.4.1 DSKTAPE

This program copies data files created by a real-time data collection run from a disk file to a 9-track file. Inputs to this program include the patch ID, geometry ID, and site name. Outputs from this program are geometry files copied on 9-track magnetic tape.

8.4.2 RESTAPE

This program copies (restores) real-time data files from a 9-track tape to disk files. Inputs include the patch ID, geometry ID, the site name, and a file on 9-track tape. The output is a geometry file on the MASSCOMP disk with the correct name.

8.4.3 Quick Look Data Processing of Terrain Data

Once the real-time data are collected, it is desirable to verify the necessary information that was gathered. A program was written to take a quick-look at the data which were collected to verify the hardware and software are functioning correctly and that the parameters specified by the set up program are correct. Quick-look processing has several options to produce various checks of the data.

8.4.3.1 Geometry Information. The geometry information contains a record of the input parameters received from the set up program and any changes made to these parameters by the real-time data collection program. This listing defines the nominal positions of the ships and how the data were sampled. There are several groups of data contained in this option.

Nominal Position Information

The positions are specified in one of two ways: reference coordinates or MLS coordinates. A sample of the compuer printout containing this information is shown below. The reference coordinate system is a true earth system with its origin at a known reference. This reference is the south west corner of the digital map used by the set up routine. Points in the reference system are specified as feet east of the reference, feet north of the reference, feet above mean sea level. The MLS coordinate system is based on the MLS center line and has its origin at the MLS. Points in the MLS system are specified feet forward of the MLS, feet left of the MLS, feet above the MLS.

```
POSITION INFORMATION

    POSITIONS IN REFERENCE COORDINANTS ARE IN FEET (EAST, NORTH, UP).
    POSITIONS IN MLS COORDINANTS ARE IN FEET (FORWARD, LEFT, UP).

               MLS POSITION (RELATIVE TO REFERENCE) = ( 34176, 51579,  2074)
    MLS CENTER LINE BEARING (RELITIVE TO TRUE NORTH) =   113

                         DME CORRECTION (FEET) =  85.0
                     COMPASS CORECTION (DEGREES) = -13.6

          SPECULAR POSITION (RELATIVE TO REFERENCE) = ( 41507, 40376,  2765)

    REFERENCE LIGHT POSITION (RELATIVE TO REFERENCE) = (     0,     0,     0)

    CHECK POINT ONE POSITION (RELATIVE TO REFERENCE) = (     0,     0,     0)
    CHECK POINT TWO POSITION (RELATIVE TO REFERENCE) = (     0,     0,     0)

    DESIRED RECEIVER SHIP POSITION (RELATIVE TO MLS) = (  8000, -3260,  1401)
  DESIRED TRANSMITTER SHIP POSITION (RELATIVE TO MLS) = (  8000,  3260,  1401)

                       SPECULAR ANGLE (DEGREES) =  26
```

Scan Information

The scan information defines, for the receive antenna, which azimuths were scanned and at which elevations in these azimuths data were collected. The azimuths are specified relative to the receiver, with 0 degrees being directly out of the side (90 degrees clockwise from the aircraft heading) and positive angles measured clockwise. Elevations are specified as depression angles with 0 degrees being horizontal and positive angles measured downward. All sampling is currently done at 2-degree increments for terrain data. An example of the computer printout with the receive antenna scanning information follows.

```
SCAN INFORMATION

                     NUMBER OF AZIMUTHS =  11
      STARTING AND STOPING AZIMUTH INDEX =  13    23
    NOMINAL STARTING AND STOPING AZIMUTHS =  -6    14
 NOMINAL STARTING AND STOPING ELEVATIONS =   2    30

          AZIMUTH (DEGREES) =   -6   -4   -2    0    2    4    6    8   10   12   14
STARTING ELEVATION (DEGREES) =   20   20   18   18   18   20   20   20   22   22   24
 STOPING ELEVATION (DEGREES) =   30   30   30   30   30   30   30   30   30   30   30
```

Sampling Information

The sampling information includes the parameters used to define the procedure for data sampling. For each azimuth the delay generator is loaded with delays relative to the timing pulse (1800 nsec before main bang). The first delay loaded is the "Starting Delay". The next delay is "Starting Delay" + "Delay Delta". Subsequent delays may be found by repeatedly adding "Delay Delta". The last delay loaded is "Starting Delay" + ("Number of Delays" - 1) times "Delay Delta". Along with the delay information, the pulsewidth of the transmitter and filter used in the receiver are specified. The filter number indicates the filter used. Filter number 1 is 20 MHz, number 2 is 85 MHz, and number 3 is 250 MHz. An example of the computer printout follows.

```
SAMPLING INFORMATION

TIME OF ARRIVAL FOR DIRECT BEAM (NSEC) =        0
                 AZIMUTH (DEGREES) =    -6    -4    -2     0     2     4     6     8    10    12    14
             STARTING DELAY (NSEC) =  2700  2749  2802  2796  2817  2760  2796  2842  2792  2831  2844
                DELAY DELTA (NSEC) =   -20   -20   -10   -10   -10   -10   -10   -10   -10   -10   -10
                  NUMBER OF DELAYS =    17    16    37    36    38    32    35    38    30    31    29
                 PULSEWIDTH (NSEC) =    20    20    20    20    20    20    20    20    20    20    20
                     FILTER NUMBER =     3     3     3     3     3     3     3     3     3     3     3
```

Test Point Information

There are ten test points for which the azimuth and elevation of the transmitter and receiver are given. When the azimuths and elevations are set to the specified values, the test point should be in view of the camera if the ship is in the desired position. The azimuths are specified in degrees from true north and elevations are degrees of depression. The time of arrival via each test point is also given.

```
TEST POINT INFORMATION

 TEST POINTS - 1 -> REFERENCE LIGHT
               2 -> OTHER HELICOPTER
               3 -> MLS
               4 -> SPECULAR
               5 -> +2 DEGREES ELEVATION FROM SEPCULAR
               6 -> -2 DEGREES ELEVATION FROM SEPCULAR
               7 -> +2 DEGREES AZIMUTH FROM SEPCULAR
               8 -> -2 DEGREES AZIMUTH FROM SEPCULAR
               9 -> CHECH POINT ONE
              10 -> CHECH POINT TWO

 AZIMUTHS ARE GIVEN IN TRUE NORTH COORDINANTS AND ELEVATIONS ARE GIVEN AS DEPRESSION ANGLES.

                      POINT INDEX =       1      2      3      4      5      6      7      8      9     10
   TRANSMITTER AZIMUTH (DEGREES) =     220    204    271    204    204    204    202    206    220    220
 TRANSMITTER ELEVATION (DEGREES) =       4      0     10     26     24     20     26     26      4      4
      RECEIVER AZIMUTH (DEGREES) =     222     24    316     24     24     24     26     22    222    222
    RECEIVER ELEVATION (DEGREES) =       4      0     10     26     28     24     26     26      4      4
TIME OF ARRIVAL VIA TEST POINT (NSEC) = *******  576004916990 127596 128603 128940 128525 128525**************
```

Pointing Information

The point information for the transmitter is specified. Currently the transmitter is pointed at the nominal geometric specular.

POINTING INFORMATION

TRANSMITTER BEAM AZIMUTH (RELATIVE TO TRUE NORTH) = 203
TRANSMITTER BEAM ELEVATION (DEPRESSION ANGLE) = 26
TRANSMITTER BEAM AZIMUTH (RELATIVE TO CENTER) = 0

Gain Information

Since terrain signal strength will vary with polarization and especially out-of-plane angle, attenuators were used to attenuate the high-level signals. The attenuations used for each azimuth and polarization are specified. A different attenuation may be set for the horizontal/right and the vertical/left receiver channels. The first number listed is the front end attenuator setting, the second corresponds to the second attenuator setting.

GAIN INFORMATION

POLARIZATION INDEX =											
AZIMUTH (DEGREES) =	-6	-4	-2	0	2	4	6	8	10	12	14
HORIZONTAL ATTENUATION =	10 00	20 00	20 00	20 00	20 00	20 00	10 00	00 00	00 00	00 00	00 00
VERTICAL ATTENUATION =	10 00	20 00	20 00	20 00	20 00	20 00	10 00	00 00	00 00	00 00	00 00

POLARIZATION INDEX =											
AZIMUTH (DEGREES) =	-6	-4	-2	0	2	4	6	8	10	12	14
HORIZONTAL ATTENUATION =	10 00	20 00	20 00	20 00	20 00	20 00	10 00	00 00	00 00	00 00	00 00
VERTICAL ATTENUATION =	10 00	20 00	20 00	20 00	20 00	20 00	10 00	00 00	00 00	00 00	00 30

POLARIZATION INDEX =											
AZIMUTH (DEGREES) =	-6	-4	-2	0	2	4	6	8	10	12	14
HORIZONTAL ATTENUATION =	10 00	20 00	20 00	20 00	20 00	20 00	10 00	00 00	00 00	00 00	00 00
VERTICAL ATTENUATION =	10 00	20 00	20 00	20 00	20 00	20 00	10 00	00 00	00 00	00 00	00 00

Range Ring Information

The number of range rings to be collected at each gulp is given. A gulp is defined as a window of data collected at a given azimuth and elevation angle of the boresight of the receive beam footprint for a given polarization. The rings samples for each gulp are collected at consecutive delays. Typically, there are 2 rings per pulsewidth.

RANGE RING INFORMATION

Elevations = Azimuths	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
-6	0	0	0	0	0	0	0	0	0	7	16	16	13	14	6
-4	0	0	0	0	0	0	0	0	0	7	14	14	13	13	7
-2	0	0	0	0	0	0	0	0	7	30	27	26	23	24	11
0	0	0	0	0	0	0	0	0	6	29	27	26	22	23	10
2	0	0	0	0	0	0	0	0	6	31	28	25	22	23	10
4	0	0	0	0	0	0	0	0	0	13	30	26	23	24	11
6	0	0	0	0	0	0	0	0	0	11	32	28	24	25	11
8	0	0	0	0	0	0	0	0	0	9	34	29	25	24	11
10	0	0	0	0	0	0	0	0	0	0	16	30	26	26	12
12	0	0	0	0	0	0	0	0	0	0	14	30	28	26	12
14	0	0	0	0	0	0	0	0	0	0	0	16	28	27	12

Sample Rate Information

As was discussed in Section 2, one sample of the terrain is taken each PRI. However, it is typical that multiple samples (over multiple PRI) will be taken at the same delay with respect to direct. The number of samples taken at each delay for each gulp is listed in the computer printout, an example of which follows. These samples may be averaged or one may be chosen to represent the signal level at each delay for each gulp.

SAMPLE RATE INFORMATION

Elevations = Azimuths	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
-6	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
-4	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
-2	0	0	0	0	0	0	0	0	10	6	7	7	8	8	10
0	0	0	0	0	0	0	0	0	10	6	7	7	8	8	10
2	0	0	0	0	0	0	0	0	10	6	6	7	8	8	10
4	0	0	0	0	0	0	0	0	0	10	6	7	8	8	10
6	0	0	0	0	0	0	0	0	0	10	6	7	8	8	10
8	0	0	0	0	0	0	0	0	0	10	5	6	7	8	10
10	0	0	0	0	0	0	0	0	0	0	10	6	7	8	10
12	0	0	0	0	0	0	0	0	0	0	10	6	7	7	10
14	0	0	0	0	0	0	0	0	0	0	0	10	6	7	10

Starting Delay Information

The delay of the first ring to be collected for each gulp is specified. This information was passed to the delay generator during the real-time data collection. The first ring is sampled at the delay listed, the next ring at the next delay and so on. The number listed is the index of the delay to be used in the vector of delays stored in the delay generator. For information on the vector of delays stored see "Sampling Information".

STARTING DELAY INFORMATION

ELEVATIONS = / Azimuths	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
-6	0	0	0	0	0	0	0	0	0	7	1	3	5	4	11
-4	0	0	0	0	0	0	0	0	0	6	1	3	4	4	10
-2	0	0	0	0	0	0	0	0	17	1	8	12	15	14	26
0	0	0	0	0	0	0	0	0	17	1	8	12	16	14	26
2	0	0	0	0	0	0	0	0	19	1	9	14	17	16	28
4	0	0	0	0	0	0	0	0	0	12	1	7	10	9	21
6	0	0	0	0	0	0	0	0	0	15	1	8	12	11	24
8	0	0	0	0	0	0	0	0	0	18	1	10	14	14	27
10	0	0	0	0	0	0	0	0	0	0	11	1	5	6	19
12	0	0	0	0	0	0	0	0	0	0	12	1	4	6	20
14	0	0	0	0	0	0	0	0	0	0	0	11	1	3	18

Angle Delta Information

The delta from the nominal angle in hundredths of degrees is specified. Sampling for the gulp begins at this angle match. This is used to modify the angle match at which the data are collected.

ANGLE DELTA INFORMATION

Elevations = / Azimuths	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
-6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-2	0	0	0	0	0	0	0	0	2	4	4	4	4	4	2
0	0	0	0	0	0	0	0	0	1	4	4	4	4	4	2
2	0	0	0	0	0	0	0	0	1	4	4	4	4	4	2
4	0	0	0	0	0	0	0	0	0	3	4	4	4	4	2
6	0	0	0	0	0	0	0	0	0	2	4	4	4	5	2
8	0	0	0	0	0	0	0	0	0	2	4	4	4	4	2
10	0	0	0	0	0	0	0	0	0	0	4	4	4	5	3
12	0	0	0	0	0	0	0	0	0	0	3	4	4	4	3
14	0	0	0	0	0	0	0	0	0	0	0	4	4	4	3

8.4.3.2 Actual Position Information. The position information is listed to check the operation of the MLS, the deviation from the nominal position, the accuracy of the antenna positioning and the functioning of the antenna stabilization system. The following information is produced for each gulp.

Nominal azimuth, elevation, transmit and receive polarizations (AZ, EL, X POL and R POL) - fixed values used to identify the gulp.

Receiver and transmitter MLS values (RCV MLS and XMT MLS) - These are the MLS measured azimuth (AZ), elevation (EL) and range (RNG) to the receiver and the transmitter. The azimuth and elevation are in degrees. The range is in feet but contains an 85-foot bias. The correction formula for the MLS is not applied here.

Receiver and transmitter position RCV POS and XMT POS) - These are x, y, z positions of the receiver and the transmitter in MLS coordinates. All values are specified in feet. The altitude given here is with respect to the MLS.

Receiver antenna pointing - This is the heading of the receiver ship (HDG) specified in true earth coordinates. This is obtained by adding the compass correction to the magnetic heading provided by the ship's gyro. The pitch (PTCH) and roll (ROLL) errors are specified in degrees. These are errors introduced by the lag in the stabilization system. The receiver azimuth (AZ) is specified in degrees relative to the antenna scan center (90 degrees clockwise from the ships heading). The receiver elevation (EL) is specified in degrees of depression relative to horizontal. The effects of the pitch and roll errors are not included in the values for azimuth and elevation. The receiver azimuth relative to the plane between the receiver and the transmitter, perpendicular to the earth is given in degrees (TAZ). See Figure 76. The footprint extent (FP), in nanoseconds, is listed for reference. For each azimuth scan a statistical summary of the receiver azimuth and elevation data are supplied. An example of the position information follows.

HDG IS RELATIVE TO TRUE NORTH
PNT IS RELATIVE TO HELICOPTER FORWARD
AZ IS RELATIVE TO DESIRED PLANE TO THE XMT
TAZ IS RELATIVE TO ACTUAL PLANE TO THE XMT
MLS CENTERLINE IS RELATIVE TO TRUE NORTH

AZ = -[(MLS-90)-HDG-PNT]
= 90+HDG+PNT-MLS

TAZ = -[XMT-HDG-PNT]
= HDG+PNT-XMT

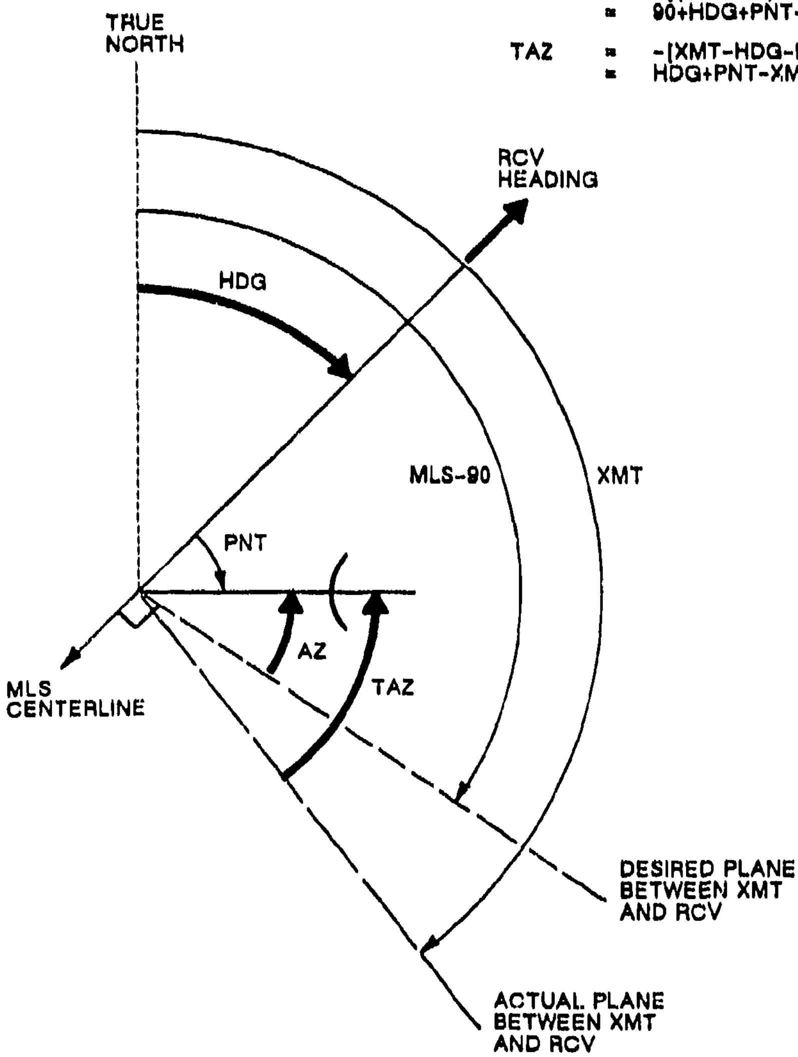


Figure 76 STATIC GEOMETRY AZIMUTH ANGLE DEFINITIONS

AZ	EL	X R POL	RCV MLS AZ	RCV MLS EL	RCV MLS RNG	XMT MLS AZ	XMT MLS EL	XMT MLS RNG	RCV POS X	RCV POS Y	RCV POS Z	XMT POS X	XMT POS Y	XMT POS Z	HDG	RCV ANTENNA POINTING PNT	PTCH	ROLL	AZ	EL	TAZ	FP
-6	20	L	-21.7	10.3	8090	21.0	10.5	8033	8141.	-3246.	1490.	8005.	3231.	1490.	299.0	78.0	0.6	-0.2	-4.4	20.0	-3.9	106
-6	22	L	-21.8	10.3	8891	21.7	10.5	8700	8137.	-3255.	1496.	8039.	3206.	1479.	298.9	79.8	0.8	0.8	-4.2	22.0	-3.4	57
-6	24	L	-21.8	10.3	8898	21.8	10.5	8825	8145.	-3256.	1495.	8000.	3223.	1487.	298.6	79.7	0.4	2.1	-4.7	24.0	-4.2	36
-6	26	L	-21.8	10.3	8875	21.8	10.6	8770	8124.	-3248.	1492.	8027.	3204.	1490.	299.1	78.7	0.0	2.3	-5.1	26.0	-4.3	21
-6	28	L	-21.8	10.2	8870	21.8	10.6	8817	8128.	-3249.	1482.	8069.	3222.	1499.	299.8	78.2	0.4	0.6	-5.1	28.0	-4.5	18
-6	30	L	-21.8	10.2	8904	21.7	10.6	8782	8155.	-3253.	1483.	8048.	3198.	1603.	299.5	78.7	0.6	-0.8	-4.9	30.0	-3.9	20

TRUE AZIMUTH MEAN, SD, MIN, MAX, RANGE, DES -4.7 0.4 -5.1 -4.2 0.9 -6.0
TRUE ELEVATION ERROR MEAN, MSS, MIN, MAX, RANGE 0.0 0.0 0.0 0.0 0.0

For each geometry, a statistical summary of the position data is provided. The mean position of each ship is computed and presented along with the standard deviation, the minimum, the maximum, the range, and the desired position. An example of this statistical summary follows.

	MEAN	STANDARD DEVIATION	MINIMUM	MAXIMUM	RANGE	DESIRED
TRANSMITTER X	8059.12	68.22	7836.46	8226.01	389.55	8000.00
TRANSMITTER Y	3241.47	31.97	3167.79	3313.87	146.08	3260.00
TRANSMITTER Z	1492.85	38.06	1412.06	1592.58	180.52	1481.00
RECEIVER X	8088.43	90.00	7900.84	8275.19	374.35	8000.00
RECEIVER Y	-3334.42	64.39	-3513.87	-3235.83	278.04	-3260.00
RECEIVER Z	1524.91	31.03	1446.81	1592.87	146.05	1481.00
HEADING	301.51	3.98	292.89	311.33	18.44	-67.00

8.4.3.3 Time of Arrival Information. The time of arrival information is used to check that the time of arrival for the signal is within the sampling window. The time of arrival for the signal is computed using the actual positions of the helicopters and the actual pointing of the receiver antenna. Since quick-look processing does not use a terrain map, there may be some difference between the computed time and the real time of arrival. If, however, the terrain is not too rough, this information will provide a good reference for cushion adjustments and a good indication of problems. The following information is provided for each gulp. A sample of the computer printout follows.

Nominal azimuth, elevation, transmit and receive polarizations (AZ, EL, X POL and R POL) - fixed values used to identify the gulp, based on the nominal or desired values.

Expected time of arrival (EXPECTED TOA) - The time of arrival, in nanoseconds, for the boresight if the transmitter and receiver ship are in their desired positions and the receive antenna is pointing at the nominal azimuth and elevation.

Sampling window (WINDOW) - The first time sampled for the gulp (START), the last time samples for the gulp (STOP) and the sampling increment for the gulp (DEL) are given in nanoseconds.

Expected time of arrival for the specular - The time of arrival for the geometric specular, in nanoseconds, given the actual helicopter positions is listed TOA (expected for specular). The difference between this time and the expected time of arrival for the boresight is also given in nanoseconds (TOA ERR). The sampling error (SMP ERR) is the number of nanoseconds to the closest window edge (either STOP or START). If the sampling error is followed by an '*', the specular time of arrival is within the sampling window. If the sampling error is followed by a '-', the time is before the window. If the sampling error is followed by '+', the time is after the window. Gulps whose sampling error is followed by an '*' should contain specular data.

Computed time of arrival for the boresight - The time of arrival computed for the boresight, in nanoseconds, using the actual position of the helicopters and the actual pointing of the receive antenna (excluding pitch and roll correction). The difference between this time and the expected time of arrival of the boresight is also given in nanoseconds (TOA ERR). The sampling error (SMP ERR) is the number of nanoseconds from the boresight time of arrival to the closest window edge (either STOP or START). If the sampling error is followed by a '*', the boresight time of arrival is within the sampling window. If the sampling error is followed by a '-', the time is before the window. If the sampling error is followed by a '+', the time is after the window. Gulps whose sampling errors are followed by an '*' should contain boresight data from the specular angle.

Boresight ring - The range ring the boresight time of arrival falls in.

Peak sum vertical/left circular ring - The range ring the peak signal in the sum vertical or sum left circular signal is received.

Peak sum horizontal/right circular ring - The range ring the peak signal in the sum horizontal or sum right circular signal is received.

Computed time of arrival for the principal peak - The time of arrival for the principal sum peak, in nanoseconds, is computed using the ring in which the appropriate sum channel peaks. The difference between this time and the expected time of arrival of the specular is also given in nanoseconds (TOA ERR). The sampling error (SMP ERR) is the number of nanoseconds to the closest window edge (either STOP or START). The sampling error will be followed by an '*' since the peak is within the sampling window. Since the peak signal is typically at the specular angle, the sampling error should be close to zero for the gulps containing specular data.

			EXPECTED	WINDOW (NS)			EXPECTED TOA FOR SPECULAR				COMPUTED TOA FOR BORESIGHT				BORE-SIGHT	PEAK SUM V/L	PEAK SUM H/R	COMPUTED TOA FOR PRINCIPAL PEAK			
AZ	EL	TPOL	TOA	START	STOP	DEL	TOA	TOA ERR	SMP ERR		TOA	TOA ERR	SMP ERR		RING	RING	RING	TOA	TOA ERR	SMP ERR	
-6	20		876.	740.	860.	20.	762.	-114.	22.	*	864.	-12.	4.	*	6	6	3	840.	70.	20.	*
-6	22		818.	780.	980.	20.	761.	-57.	61.	*	803.	-15.	103.	*	5	8	8	840.	79.	140.	*
-6	24		790.	660.	940.	20.	763.	-27.	103.	*	786.	-4.	126.	*	6	10	10	840.	77.	100.	*
-6	26		779.	660.	900.	20.	765.	-14.	105.	*	779.	0.	119.	*	6	10	10	840.	75.	60.	*
-6	28		778.	660.	920.	20.	763.	-15.	103.	*	779.	1.	119.	*	6	10	10	840.	77.	80.	*
-6	30		785.	680.	700.	20.	760.	-17.	12.	*	786.	1.	6.	*	5	4	3	740.	-20.	40.	*

8.4.3.4 Printer Plot. A printer plot may be generated to examine the signal levels received during real-time data collection In-phase, quadrature or the square root of the sum of the squares of both may be plotted for either the first or the average of the samples. The ten rings centered on the peak of the principal sum channels are plotted. Each symbol represents a voltage. The symbols are ordered '0' to '9', 'a' to 'z', 'A' to 'Z' with voltage increasing from 0 to Z.. The voltage may be computed by taking the ordinal position of the symbol (ordinal of '0' = 0, of

'1' = 1 . . . of '9' = 9, of 'a' = 10 . . . of 'z' = 35, of 'A' = 36 . . . of 'Z' = 61), multiplying it by the step size and adding the minimum for the plot. An '*' means the sample is missing or the sample's magnitude is higher than the system is capable of measuring. A '+' means the sample is higher than the level represented by 'z'. The plots may be thresholded to replace symbols '0' to '9' with blanks. This can be useful in locating big signals. A '-' means the sample is less than the minimum for the plot or less than the level represented by 'a' if the plot is thresholded.

```
TERRAIN MEASUREMENTS          MILESCITYMON              Flight #148
SAT DEC  5 10:25:14 1987   Patch id = 8A   Geometry id = 1     Average
TRANSMIT POLARIZATION =                      RECEIVER POLARIZATION = *****
MINIMUM FOR PLOTS =  0 (MVOLTS)           STEP SIZE FOR PLOT = 10 (MVOLTS)
                          ROOT SUM OF SQUARES
```

	10	12	14	16	18	20	22	24	26	28	30
-6						1217bp*	100jv66221	1121+63111	1111qd220*	12jaf5312*	01011*
-4						*00064	0000a11000	00000a2100	000000m100	000000f210	*000000
-2					00000010	1121321110	0134534100	05^6750121	0000h54311	0004c44110	0000000000
0					000000	0100201110	12a5eb4301	00699a3211	000004cdb0	00003hd211	0000000000
2					000001	0113032210	0001013100	0000021100	0000000000	0000000211	0000000000
4						0000000001	0010000011	0000001110	0000000000	0000001213	0000000000
6						0000000000	0001431231	0000561010	0000000125	0100000961	0100000010
8						134ha7476	213af4bb84	27a4e54722	7g18bf2e5t	bg7a3289jt	2142033122
10							210115fba7	136moc6683	321ahbd4d7	017dh74961	1211210100
12							0103f25d95	3340334283	3403c67812	5984d9c422	2211011117h
14								db73486632	143g35272b	21579b894h	236a71bn9b

8.4.3.5 Peak Plot. A plot of the peak signal collected at each elevation for a given azimuth and polarization may be drawn to provide information on how the signal level changes as a function of elevation. See Figure 77.

8.4.3.6 Scan Plot. A plot of the antenna scan pattern can be generated to verify the functioning of the antenna control unit and the antenna stabilization system. The points at which the boresight ray from

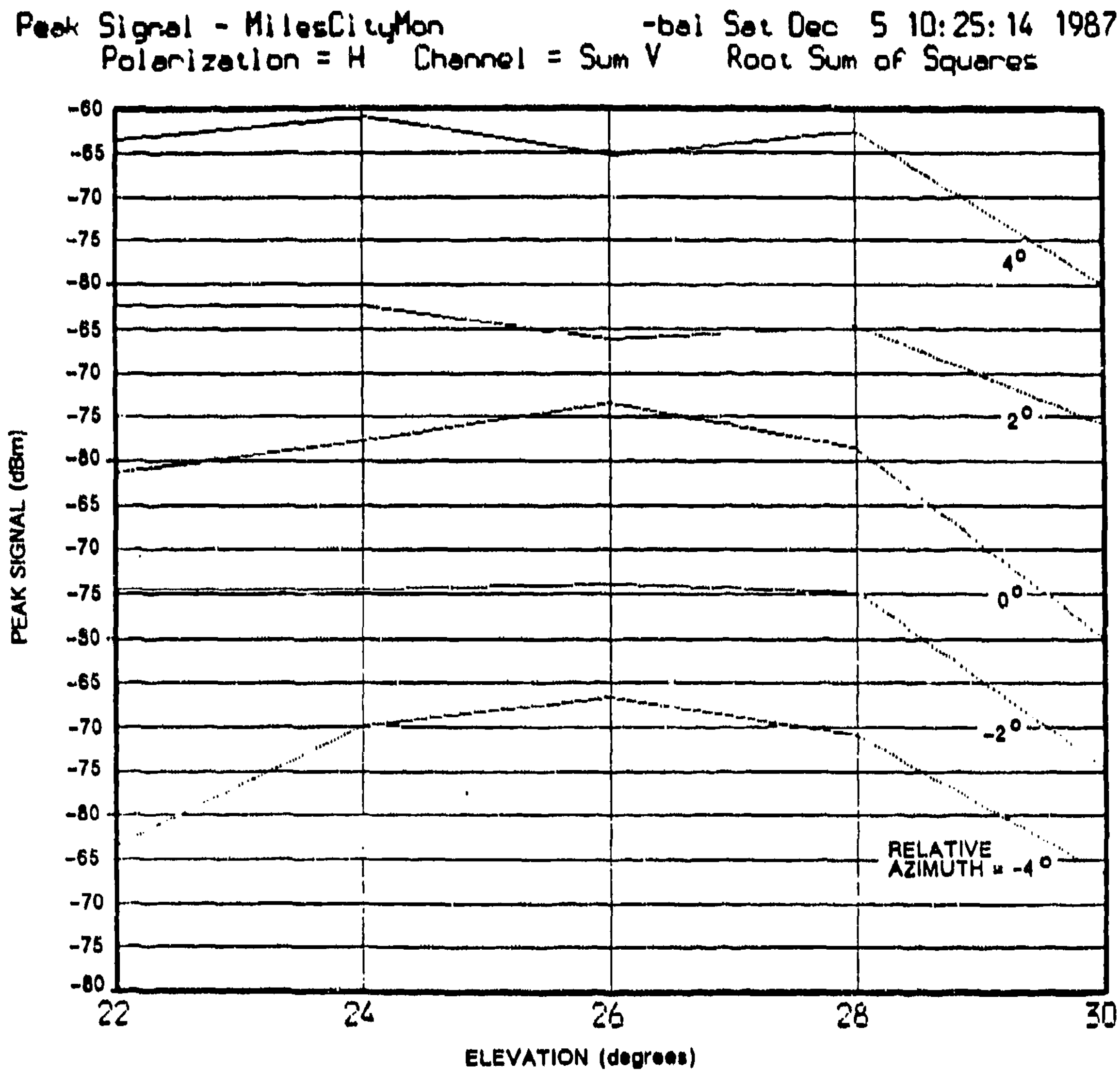


Figure 77 PEAK SIGNAL PLOT

the receiver intersects flat earth (at specular height) are plotted. See Figure 78.

8.4.3.7 Raw Data. The raw data collected can be listed in millivolts if the exact signal level needs to be examined. Data for each ring collected at each Az, El, Pol combination is listed.

```
          POL = V AZ =  -2 EL = 24 CHAN = 1
     [illegible] -72.0 -80.0 -80.0 -80.0 -80.0 -75.9 -75.1 -80.0 -75.1 -80.0 -74.5 -80.0 -80.0 -80.0 -86.0 -73.1 -67.1 -54.1 -53.9
[illegible] 47.9 -64.3 -69.9 -75.3 -71.0

          POL = V AZ =  -2 EL = 24 CHAN = 2
     80.0 -80.0 -80.0 -80.0 -80.0 -80.0 -75.9 -80.0 -80.0 -80.0 -72.8 -80.0 -75.9 -73.9 -80.0 -76.3 -80.0 -80.0 [illegible] [illegible]
[illegible] 46.7 -63.0 -65.8 -65.1 -72.7

          POL = V AZ =  -2 EL = 24 CHAN = 3
     [illegible] -74.8 -80.0 -80.0 -73.5 -75.8 -73.4 -76.5 -80.0 -73.6 -72.1 -80.0 -80.0 -80.0 -75.4 -80.0 -74.7 -70.6 -47.0 [illegible]
[illegible] 74.8 -62.5 -65.4 -68.9 -70.5

          POL = V AZ =  -2 EL = 24 CHAN = 4
     -80.0 -80.0 -80.0 -80.0 -80.0 -80.0 -80.0 -76.3 -80.0 -80.0 -75.2 -80.0 -80.0 -80.0 -76.5 -80.0 -80.0 -80.0 [illegible] -64.0
[illegible] 64.6 -74.4 -80.0 -80.0 -75.4

          POL = V AZ =  -2 EL = 24 CHAN = 5
     -80.0 -80.0 -72.0 -80.0 -80.0 -80.0 -80.0 -80.0 -80.0 -80.0 -80.0 -80.0 -80.0 -80.0 -80.0 -82.0 -76.2 -80.0 -62.9 -70.4
[illegible] 55.3 -64.3 -66.2 -72.4 -80.0

          POL = V AZ =  -2 EL = 24 CHAN = 6
     -80.0 -80.0 -67.0 -71.6 -69.6 -80.0 -73.6 -66.0 -80.0 -80.0 -67.4 -71.1 -69.1 -80.0 -73.0 -69.4 -66.9 -67.0 -64.4 -67.7
[illegible] 58.2 -65.6 -72.6 -60.6 -68.3
```

8.4.3.8 Ring Plot. A ring plot is the time history of the signal for a gulp of real-time data. See Figure 79.

All of the above are performed for in-phase, quadrature or both. The signal levels used are then those received in the in-phase or quadrature channels, or the root sum of the squares of both if the "both" option is selected. It is possible to process the data by either choosing the first sample collected or to average all the samples. The data may be processed using a calibration run to remove the sampler offsets and the gains. Currently, examination of the square root of the sum of squares of the averaged, calibrated samples is considered most useful.

8.4.3.9 Reduced Data Files. Quick-look processing will write three files which are used in further data reduction. The file used as input to to quick-look processing is essentially a time history of the data

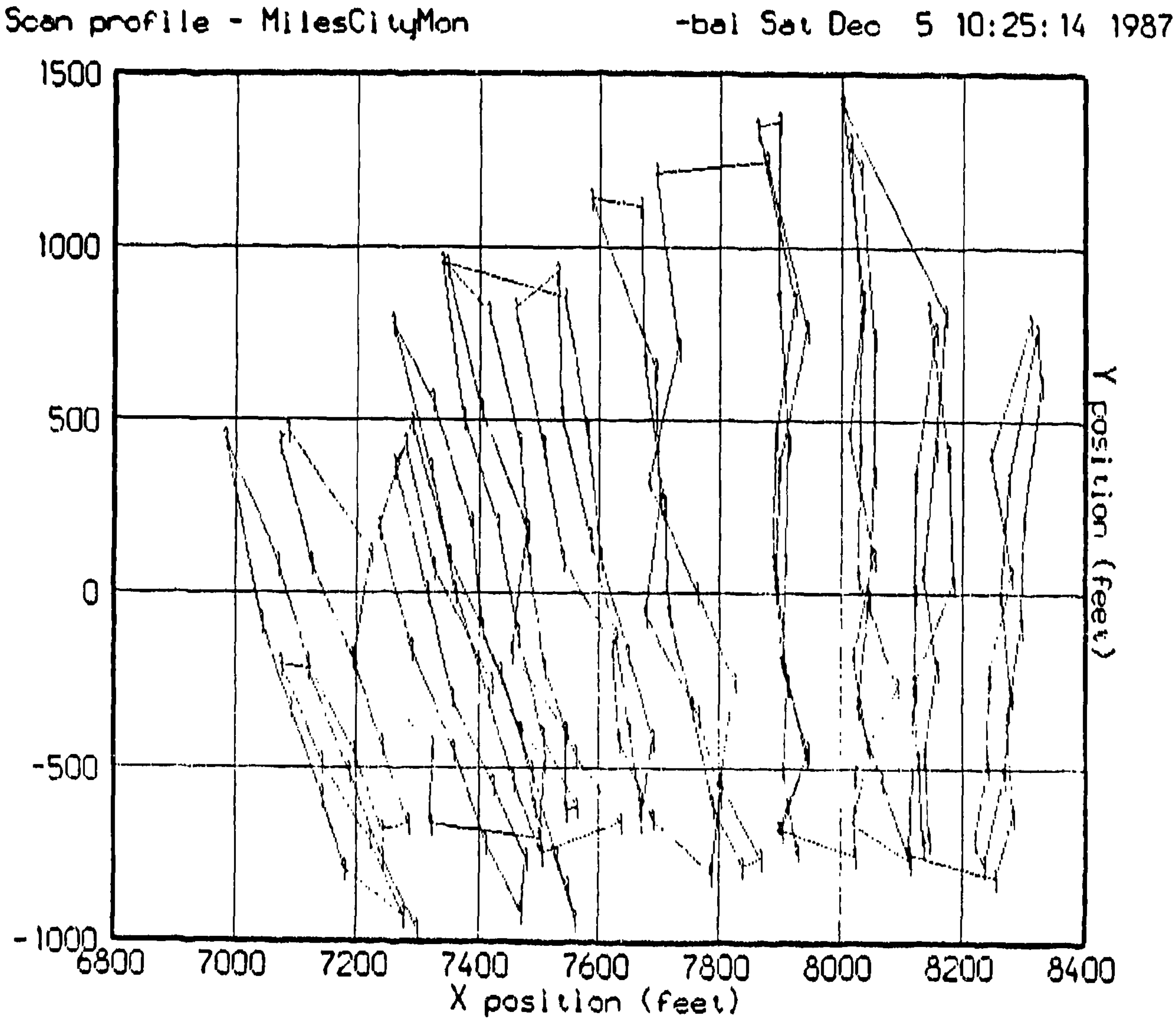


Figure 78 SCAN PROFILE PLOT

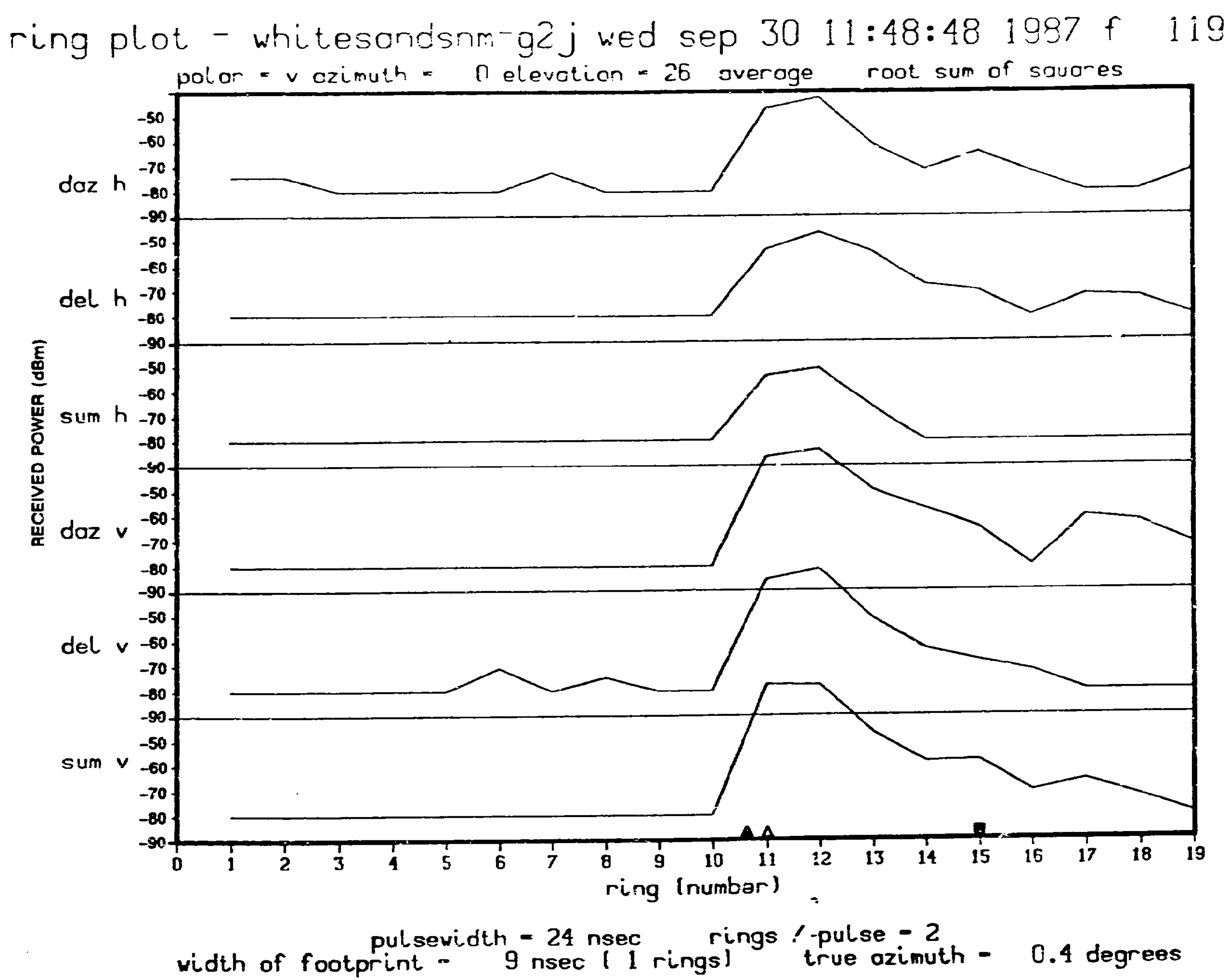


Figure 79 RING PLOT

collected during a run of the real-time data collection program. Quick-look processing rearranges these data into an azimuth, elevation, polarization matrix. The first file produced is DA2 which contains the raw sampler data collected. The next file is IN1 which contains position information and receiver pointing information. The final file, BIAS, contains calibration information.

8.4.4 Quick-Look Data Processing of Direct Path Data

Direct path data is collected to check the system calibration. Both bias runs and direct data runs are processed in the same fashion. The data processing for these two types of runs is a subset of the terrain quick-look processing. Only ring plots and position data are produced.

8.4.5 Quick-Look Data Processing of Calibration Data

A bias run of quick-look processing will produce two files. Both will contain a listing of the sampler offsets and the gains to calibrate the signal data. One is readable text to be examined and the other is computer formatted data to be used by terrain quick look processing.

8.5 TRANSMITTER

The transmit software is run on the Mostec computer installed on the transmit ship. During real-time data collection this program provides the functions necessary to support data collection and recording. The functions provided by the transmitter software can be divided into two general categories: control of data communication with the receiver and control of the transmitter helicopter systems.

8.5.1 Control of Data Communication

The transmit software handles the reception of commands from the receiver and the sending of data to the receiver. The input buffer which holds commands from the receiver is continually checked for new commands. When a command is found, the appropriate action is taken. When the receiver requests data the transmitter sends the requested sequence.

During real-time data collection, the transmitter will receive commands from the receiver. Commands can also be entered from the Mostec keyboard when unavailable from the receiver. The commands consist of a control character followed by an optional argument and terminated by a carriage return. The commands are presented in Table 9.

Four commands deal with the sending of information to the receiver: "H", "L", "S" and "U". The "S" command is used to set up the channel sequence which will be sent when high or low speed data is requested. The "S" command will execute a routine which prompts the operator at the console to indicate a new sequence of digital and analog channel numbers for the high or the low speed data. When the receiver requests high or low speed data, the sequence of data is sent in the order specified by the "S" command.

The low speed data is requested by the "L" command. The receiver will request low speed data when it is required. The system does not use low speed data in its current configuration. When low speed data is requested, the transmitter sends the data designated in the low speed sequence to the receiver. Since the current system does not use low speed data, the default low speed sequence is empty.

The high speed data are requested by the "H" command. The receiver will request high speed data when it is required. The system requests high speed data once per gulp in its current configuration. When high speed data is requested, the transmitter sends the data designated in the high speed sequence to the receiver. The default high speed sequence includes the MLS information indicating the transmit ship position and the pulsewidth and polarization of the transmitted pulse.

Table 9. Transmitter Commands

Control Character	Argument	Function
A	Prepulse advance	Set the number of microseconds by which the prepulse precedes the main bang
B	—	Enable main bang
C	Center line of MLS	Set the center line of the MLS in tenths of degrees relative to true north
D	Desired helicopter heading	Set the desired helicopter heading in tenths of degrees relative to true north
E	Elevation of antenna	Set the depression angle of the transmit antenna in tenths of degrees relative to horisontal (positive angle indicates down look)
F	MLS range correction	Set the MLS range correction in feet
G	Relative asimuth of Antenna	Set the asimuth of the transmit antenna in tenths of degrees relative to the ships heading (use exclusive of command T)
H	—	Send high speed data to the receiver
I	Pulse repetition frequency	Set the PRF in hundreds of pulses per second
J	—	—
K	Compass correction	Set the compass correction in tenths of degrees
L	—	Send low speed data to the receiver
M	—	Enter the menu routine (not implemented)
N	—	Disable main bang
O	—	Disable prepulse
P	—	Enable main bang
Q	—	Quit transmitter program
R	Polarization code	Set the polarisation of the transmitter (Polarisation code 0 = Vertical, 1 = Horisontal, 2 = Right circular, 3 = Left circular)
S	—	Set the channel sequence for the high and low speed data
T	True asimuth	Set the asimuth of the transmit antenna in tenths of degrees relative to true north (use exclusive of command G)
U	—	Initialize the modem
V	—	—
W	Pulse width	Set the pulse width of the transmitter in nanoseconds
X	Desired X position	Set the desired X position of the transmit ship relative to the MLS in feet
Y	Desired Y position	Set the desired Y position of the transmit shit relative to the MLS in feet
Z	Desired Z position	Set the desired Z position of the transmit shit relative to the MLS in feet

The modem which is used to send data to and receive data from the receiver can be initialized using the "U" command. The "U" command is used at start up of the real-time data collection and when communications are interrupted and need to be reinitialized.

8.5.2 Control of Helicopter Systems

The transmit helicopter systems involved in real-time data collection and controlled by the transmit software can be divided into 5 subsystems: pulse generation, antenna control, position control, software control, and communication. The pulse generation subsystem controls the characteristics of the transmitted pulse. The "A", "B", "I", "N", "O", "P", "R", and "W" commands are used to control the pulse's characteristics. Information on these commands is presented in Table 9.

The antenna control subsystem provides information on the desired pointing angles of the antenna and the actual pointing angles of the antenna. This information is used to position the antenna in the desired position. The "E", "G", and "T" commands are used to specify the desired azimuth and elevation of the transmit antenna. Information on these commands is presented in Table 9. Additional information comes from the antenna positioning hardware, which indicates the actual antenna orientation, and the ship's directional gyro, which provides heading information.

The position control subsystem provides information on the desired position and actual position. This information is used to provide the pilots with the data necessary for them to attempt to locate and maintain their desired position. The "C", "D", "F", "K", "X", "Y", and "Z" commands are used to enter the data required by the position control subsystem. Information on these commands is presented in Table 9. Additional input comes from the MLS, which indicates current actual position, and the ship's directional gyro, which provides heading information.

The software control subsystem provides a way to use the transmitter software. The "M" and "Q" commands re used to control the transmitter software execution. Information on these commands is presented in Table 9.

The communication subsystem controls communication between the transmitter and receiver. This subsystem and its commands are detailed above.

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